APPLICATION OF ELECTRIC POWER TO MINES AND HEAVY INDUSTRIES

PREFACE

This book is the outcome of a course of special advanced lectures delivered at the University of London, King's College, last winter and the request from those responsible for arranging the course that I would put the material into a permanent form.

While sensible of the impossibility of doing full justice to the subject in a short course of lectures, I hope that the present book may be of service to those engaged in the use of electricity in mines and some of the heavy industries.

I have to acknowledge the kindness of many friends during the course of collecting the notes on which the lectures were based, and to thank them and many manufacturers, whose names are acknowledged in the book, for their courtesy, by which I was able to illustrate the lectures by a large number of lantern slides, and am now able to illustrate the book with a selection from them

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CHAPTER I

ELECTRICITY IN MINES

Legislation.—What is a Mine ? The law affecting mines in the United Kingdom couples them with quarries A quarry is an open working more than 20 ft deep where persons are employed in getting slate, stone, coprolites, or minerals. If the working is less than 20 ft. deep it is not a " quarry " in the eyes of the law.

When the working is covered so that access to it is given either by a shaft or by a level into the side of a hill, the working becomes a mine. For the purposes of the Acts a mine includes every shaft in the course of being sunk, and every level and inclined plane in the course of being driven, and all the shafts, levels, planes, works, tramways, and sidings, both below ground and above ground, in and adjacent to and belonging to the mine

Mines are divided into two classes. Workings for coal, stratified ironstone, mines of shale and mines of fireclay fall under the Coal Mines Act, 1911. All other mines fall under the Metalliferous Mines Regulation Act. The dates of the principal Acts are :—

The Metalliferous Mines Acts, 1872 and 1875.

The Coal Mines Regulation Acts, 1887 and 1896, have lately expired, as the Coal Mines Act, 1911, which received the Royal Assent on 16th December, 1911, and came into force on 1st July, 1912, repealed them.

In connection with legislation it is necessary to remember that factories and workshops in and about a mine are dealt with by H.M. Inspectors of Mines, who, for that purpose, are appointed Factory Inspectors

Special Rules.—The details of technical matters regarding provisions as to safety have hitherto been worked out under Special Rules imposed by the Secretary of State, which have the weight of clauses in the Act, with the advantage that they can be revised and brought up to date from time to time without setting in motion all the machinery required for the alteration of an Act. The 1911 Act is novel in that it deals by clauses with matters which have previously been dealt with by Special Rules. Powers are also taken for the imposition of General and Special Regulations in addition to the technical clauses, and such regulations may vary or amend any of the provisions above referred to. This may have been intended to cure the defect above complained of, but it does so only in part, as it does not remove the prejudice which must always exist in favour of any enactment which has had the collective wisdom of Parliament concentrated upon it.

Why should there be Special Rules for the Use of Electricity in Mines ?

1902. Departmental Committee.—In 1902 a question was raised in the House of Commons with reference to accidents that had occurred, and a Departmental Committee, consisting of three Home Office officials and three other persons, was appointed to inquire into the use of Electricity in Coal and Metalliferous Mines and the dangers attending it ; and to report what measures should be adopted in the interests of safety by the establishment of Special Rules or otherwise.

This Committee duly sat and heard evidence from fifty-six witnesses, after consideration of which they drew up a Report (Cd. 1916) dated January, 1904, in which they stated :—

" We anticipate great advantages from the use of electricity and believe that it will lessen the severity of the toil of the miners and the labour of getting coal. We are convinced of

the necessity of taking precautions against avoidable accidents, and of laying down rules for the use of electricity in mines."

The Committee attached to their Report a large number of rules, which they suggested might properly be imposed. Under the provisions of the Mines Act persons interested had the opportunity of objecting to proposed rules ; this led to very long conferences and discussions and to the rules being considerably cut about—in some cases with advantage, in other cases they were mutilated.

The rules, as amended, were agreed with the persons interested and imposed early in 1905.

The Committee had stated in their Report that "the application of electricity to mining work was still in its initial stages. The practice and opinion of engineers differs considerably, and it is therefore by no means easy or desirable to prescribe too rigidly the systems that ought to be employed." They advised that "the fullest latitude be given to the great development of electrical machinery in mining, which we believe is about to take place, and desire to record our emphatic opinion that those who are to use it, and be exposed to any dangers that may arise from it, have a right to demand that every precaution should be taken that is reasonably possible to secure their safety." They pointed out that "in the record of accidents which have occurred, the cause can almost always be traced to bad plant or arrangements," and further stated "that bad work, even in the first instance, does not save 20 per cent. of the prime cost and always ends in occasioning far more loss than the initial saving."

They emphasised four cardinal points or general principles which should govern the use of electricity in mines :—

"(1) That the electrical plant should always be treated as a source of potential danger.

"(2) A plant, in the first instance, should be of thoroughly good quality, and so designed as to ensure immunity from danger by shock or fire ; and periodical tests should be made to see that this state of efficiency is being maintained.

"(3) All electrical apparatus should be under the charge of competent persons.

"(4) All electrical apparatus which may be used when there is a possibility of danger arising from the presence of gas should be so enclosed as to prevent such gas being fired by sparking of the apparatus; when any machine is working every precaution should be taken to detect the existence of danger, and on the presence of gas being noticed such machines should be immediately stopped."

Since 1905 there has been an enormous development in the use of electricity in mines. Accidents and fatalities have naturally occurred, but, the number of fatal accidents due to the use of electricity has never reached a figure greater than 1 54 per cent. of the total number of fatal accidents in mines.

When considering this figure one must remember that there is no record of the number of mines in which electricity is employed, or the total number of persons who may be there exposed in their employment to accidents due to electricity. The 1911 Act calls for an annual return for each mine showing, among other things, the type and aggregate horse-power of electrical apparatus, so that statistics on this point will in future be available.

1909. Departmental Committee.—In October, 1909, the Secretary of State appointed another Departmental Committee, consisting of two Home Office officials and one other person, to inquire into the working of the existing Special Rules for the use of electricity in mines, and to consider whether any, and if so what, amendments are required. This Committee, after having heard evidence from thirty-six witnesses, drew up a Report (Cd. 5498) dated December, 1910, to which they attached a revised set of suggested Special Rules and expressed the following conclusion:—

"Apart from the more concise arrangement and wording of the revised rules, it will be seen that the main directions in which the requirements to be met have been strengthened are the following:

"(1) By prohibiting the use of electricity where on account of the risk of explosion such use would be dangerous.

"(2) By providing that inflammable material shall not be

used in the construction of motor rooms where there exists the risk of fire.

"(3) By more stringent regulations as regards the earthing of the outer coverings of apparatus.

"(4) By clearly setting forth the conditions to be fulfilled by switchgear.

"(5) By insisting upon the better mechanical construction of cables and apparatus.

"(6) By providing for the proper supervision of apparatus."

The new Special Rules were duly proposed, objected to, and now have been amended as agreed and published in the usual official form (202,538), 17th February, 1912.

Coal Mines Act, 1911.—While these Special Rules were being proposed the new Coal Mines Bill was considered in Parliament and was passed in December, 1911. The new Mines Act came into force in July, 1912, the new Special Rules being adopted as General Regulations with such verbal alterations as may be necessary.

Under the 1904 Special Rules there was no absolute prohibition of the use of electricity in a mine, but the conditions under which it could be used were controlled as to the pressure of the supply and the design of the apparatus.

The new Special Rules prohibit the use of electricity in certain places, and, as the use of electricity is defined as "the conversion of electricity into mechanical energy, heat, or light for the purpose of providing mechanical energy, heat, or light," it follows that the transmission of electricity is not thereby prohibited, which is important.

There is, however, a sub-section, (2), to clause 60 of the 1911 Act, which provides that "if at any time in any place in the mine the percentage of inflammable gas in the general body of the air in that place is found to exceed one and a quarter the electric current shall at once be cut off from all cables and other electrical apparatus in that place, and shall not be switched on again as long as the percentage of inflammable gas exceeds that amount."

There was much discussion over this sub-section, which was not in the original Bill as introduced in Parliament, but was put in by the Committee when considering clauses. The

figure of ½ per cent, however, then appeared instead of the 1¼ per cent as the danger point

While the Bill was before Parliament a new and beautiful form of gas detector was exploited and much advertised on the strength of laboratory tests as the thing of the moment in that it provided easy and safe means for determining such low percentages of marsh gas as had previously been in practice impossible of detection—in fact it was claimed that it promised to give certainty where before there had only been conjecture, On the strength of these tests it was claimed that 1 per cent. of gas might be fairly adopted as the danger point. With a view of giving a little margin Parliament accepted 1¼ per cent., which figure was accordingly passed and now stands in the new Act.

No sooner was the Act passed than trials with the apparatus were made under ground which proved that while the new test was quite good for coal gas, it was useless, as when tried in the mine it gave absolutely no indication of fire-damp! We now have another instance of the inadvisability of legislating on scientific matters by Acts of Parliament!

Persons Employed.—The total number of persons employed in mines in the United Kingdom, according to the returns for the year 1910, is 1,078,000, of which 1,033,000 are employed in coal mines, and of these 6,176 are females. There are further 86,000 persons employed in quarries.

It is interesting to note that of the 1,078,000 employed in mines, 80 per cent. are employed underground and 20 per cent. employed on surface. All the females above mentioned are employed on surface, as sections 45 and 46 of the 1887 Act prohibit the employment of women underground in any mine.

Fatal Accidents.—There is a very instructive appendix attached to the Report of the Departmental Committee, December, 1910, in which is set out a list of fatal accidents resulting from the use of electricity in coal mines between the 1st January, 1905, and the 30th June, 1910. During that period there were 68 separate accidents resulting in 77 deaths.

Details of the 68 accidents are set out in the Report, but

they are not classified. It is somewhat difficult to make a satisfactory classification, as several of the accidents might be included under one or more different headings, so that any classification may be arbitrary. The classification, however, set out in Table A1 may be useful Eleven of the accidents occurred in connection with coal-cutting machinery or coal-face conveyors and ten in connection with lighting circuits.

TABLE A1.

Pure accidents	1
Mischievous interference	1
Faulty hand-lamps	2
Fires in motor-houses	2
Faulty erection	2
Faulty "flame-proof" apparatus	3
Difficult to classify	3
Faulty earthing of armoured cables	6
Exposed live parts	8
Faulty earthing of apparatus	9
Ignorance of value, or disregard of use of precautions provided, *i e.*, due to no fault of the system or apparatus	15
Mechanical damage of unarmoured cables ..	16
Total	68

A short summary is also given of the fatal accidents from the 1st January, 1905, to the 15th December, 1910, which brought the number of deaths up to 83. The summary is reproduced in Table A2.

The annual increase in the number of deaths from shock is no indication of deterioration in the design or unskilful user of the apparatus, but is no doubt due to the greater increase in the use of electricity and the larger number of men who are thereby exposed to danger.

An analysis of the 68 accidents shows that the pressure of the circuits upon which they occurred was as under :—

On low pressure circuits, *i.e.*, not exceeding 250 volts	6

On medium pressure circuits, *i.e.*, normally above 250, but not exceeding 650 volts ..	52
On high pressure circuits, *i.e.*, normally above 650, but not exceeding 3,000 volts	9
On extra high pressure, *i.e.*, normally exceeding 3,000 volts	1

Of these one low pressure and two medium pressure accidents were due to fires ; the remainder were shocks.

TABLE A2.

SUMMARY OF FATAL ACCIDENTS RESULTING FROM THE USE OF ELECTRICITY IN MINES FROM 1ST JANUARY, 1905. TO 15TH DECEMBER 1910.

	1905	1906	1907	1908	1909	1910	Total
Number of deaths due to ignitions of fire-damp	—	1	—	—	9	—	10
Number of deaths due to underground fires	—	—	—	—	1	1	2
Number of deaths due to electric shock	7	6	10	15	13	20	71
Total ..	..	..	..	..	..	..	83

Two fatal accidents occurred on 120 and 150 continuous current volt circuits respectively, and were both due to faulty hand-lamps. This shows how necessary it is to use the greatest care even with low pressure apparatus, especially when contact with the person may be very good, as naturally occurs in the case of a hand-lamp.

The death rate from accidents in and about coal and metalliferous mines on the average of the ten years 1901—1910 has been 1·505 per thousand persons employed underground, and ·768 for surface workers, or a general death rate of all persons employed, both on surface and underground, of 1·356 per thousand persons employed.

The death rate for 1910 was heavier than the average, due to the explosions at Whitehaven and Hulton, where respectively 136 and 344 = 480 lives were lost, and was due to the causes shown in the following Table A3, which is based on returns compiled by H.M. Chief Inspector of Mines.

TABLE A3.

Causes of Fatal Accidents in and about Metalliferous Mines in 1910.

	Underground	Surface	per cent of total
Explosions	501		27·6
Falls of ground	658		36·2
Shaft accidents	96		5·3
Use of explosives	28		1·5
Haulages	286		15·7
Electricity	**16**	**5**	**1 15**
Machinery	19	31	2 75
Railway sidings and Tramways		72	4·0
Other causes	55	51	5 8
	1,659	159	
	1,818		100 0

On looking back to 1851 it appears the death rate was 19 per million tons of coal raised, while in 1910 it was 6 54. The death rate per thousand persons employed for five years ending 1855 was 4·301; for five years ending 1910, 1 416—an improvement of 3 to 1 in each case.

Consideration of the list of the particulars of the individual electrical accidents shows that from an engineering point of view only two can properly be considered accidental deaths; the others were all avoidable and were the result either of bad work, ignorance, or carelessness and neglect of the usual precautions. This is particularly regrettable, not only on account of the loss of life and the consequent grief caused to the relatives of the victims, but because it has enabled some persons to emphasise their opposition to the use of electricity in mines.

When one considers the quarter from which the keenest opposition has come, and the fact that opposition to the use of female labour on the surface came from the same quarter. although the women who are concerned were strongly against their employment being interfered with, one is compelled to

feel that the opposition did not arise out of a real dislike to electricity any more than the opponents objected to women on their merits, but they looked on both as labour-saving appliances, and thought that if they could restrict the user of electricity and women there would be more work for the men! Fortunately for the women they got more sympathy in Parliament than electricity did.

Some direct light is thrown on the opposition by the statement made in his quarterly report, December, 1911, by the agent of one of the men's associations in the North. After condemning the utilisation of electricity in mines, the agent is reported to have stated, "it was not only serious because of the danger, but because men of experience in steam haulage were dismissed to make room for boys to do the same work by electricity!" Reliable men, as a rule, are not dismissed, but man's work is found for them elsewhere, and it is regrettable that such a good testimonial for electricity should be handled in such a short-sighted manner.

Coal Production.—The output of coal in thousands of tons from the five principal coal producing countries of the world is shown in Table A4 from the Board of Trade Coal returns. (284-1911).

TABLE A4.

Years	United Kingdom	Germany	France	Belgium	United States
	Thousands of Tons	Thousands of Tons	Thousands of Tons	Thousands of Tons	Thousands of Tons
1907 ..	267,831	140,885	35,411	23,324	428,896
1908 ..	261,529	145,298	36,044	23,179	371,288
1909 ..	263,774	146,397	36,519	23,140	411,432
1910 ..	264,433	150,372*	37,254*	23,532	447,837*

*Provisional Figures.

The total known production of the world exclusive of brown coal or lignite in 1910 was about 1,035,000,000 tons, of which it will be noted the United Kingdom produced more than one quarter.

The tons of coal produced per person, including surface

hands, employed in coal mining in the United Kingdom for the six years 1905—1910 respectively was 282, 292, 292, 271, 266 and 257, the average for the first five years being 280·6 tons, as compared with 266 tons in 1909 and 257 in 1910.

The corresponding figures for the year 1909 in a few other countries where wages are high are—Canada, 400 ; Australia, 388 ; New Zealand, 456 ; and the United States, 538 tons.

In a few countries where the wages are low the figures are—India, 99 ; Cape of Good Hope, 57 ; Sweden, 123 ; Japan, 97 tons.

Without going into the vexed question of the statutory limitation of working hours and its effect on the output in the United Kingdom for 1910, these figures clearly indicate that when labour is expensive a better return per person employed is obtained It cannot be suggested that the British miner does so much less individually than a Canadian, Australian, &c. although admittedly he does more than an Indian or a Kaffir boy. The only reasonable explanation is that where labour is dear more machines are employed to assist the miner and to increase his usefulness, and where labour is cheap fewer machines are used. The consideration of the figures gives room for serious thought, and hope to the mechanical engineer.

The machinery must be scattered, hence electricity as the cheapest and most convenient agent for driving it must be employed where it can safely be introduced. In danger zones, where it is not safe to take electricity on account of the risks incurred through gas or dust, compressed air will be used. In most cases the more economical transmission of electricity will often decide the use of that agent for so much of the transmission as is possible, and the electrically-driven air-compressor will be located as near the work to be done as may be conveniently practicable.

These figures and facts are set out to show the immense field open and to emphasise the four cardinal points mentioned quoted above from the 1904 Report. Everyone who has the interest either of the mining or electrical industry at heart must see that it is more than ever essential that the greatest possible care should be taken to ensure the best plant being employed, the best men employed to look after it, the education of those

(*b*) Removing the mineral from its natural position, either by excavating it or, in cases where it is too hard to excavate, by drilling holes into it in which explosives can be inserted, by which it may be blasted out or loosened to facilitate removal.

(*c*) Loading the mineral into skips, tubs, trams or wagons, and transporting it along the roadways to the surface, or to the shaft bottom, by haulage, and, in some cases, raising it up the shaft to the surface by winding.

(*d*) Cleaning and preparing the mineral on the surface for market.

(*e*) Incidental to these direct operations are lighting, pumping, ventilating, the preparation of timber and other materials used in the mine, and the transport of such materials to the places in the mine where they are required to be used; the transport of men into and out of the mine, and the transport of rock and other waste material from the mine to the spoil bank or tips.

Chief Risks.—In applying electricity to these operations there are two chief risks which must be guarded against and eliminated as far as possible—

(1) Shock to persons employed;

(2) Fire by arcing or over-heating, which may cause the combustion of any explosive gases or inflammable material in the mine.

Field for Electricity.—The facility with which electricity can be transmitted and used and the very small stand-by losses are the outstanding features which recommend its adoption.

In steam plants scattered boilers are the only alternative for long steam pipes. In the one case the labour, and in the other the condensation and leakage, is excessive.

The number of boilers scattered about mines, and the cost of operating them, offers a strong inducement for the change to electric driving, but to get a good load-factor on the generating plant supplying current for such machines it is generally necessary to electrify some machinery which runs long hours; ventilating fans or pumps answer this purpose admirably.

There may be no direct gain in driving machines which operate long hours by electricity as compared with driving them by steam, but the long-hour user of such machines enables electricity to be generated or bought for the combined load of such machines and for machines operating short hours at a lesser cost than that at which power could be supplied for the two classes of machinery if dealt with separately. In other words, the combined user gives a good load-factor on the generating plant.

The earliest application of electricity in mining was for lighting, the next, about 1882, was for pumping. Both were by continuous current, for the simple reason that no alternating current motors were at that time on the market.

During the last five years progress in the electrification of mines has been chiefly along the lines of alternating current development.

C.C. versus A.C.—Continuous current motors are the more economical on circuits where speed regulation is required; they have a higher torque and are much more flexible as regards speed than alternating current motors, whose speed is determined by the frequency of the supply and the number of poles in the machine.

The advantage of alternating current in transmission, on account of the high pressures which can be so easily obtained, the absence of commutators and parts where open sparking is likely to occur, and the more robust character and greater reliability of alternating current machines in places where moisture, dust, or gas obtain, are discounted by several inconveniences and disadvantages.

A point which is not generally appreciated is that, on account of the low power-factor which obtains on mining plants, the amount of copper in the feeder-cables and distributing network will be greater in a three-phase system than in a continuous current system, with equal voltage on both systems.

Although the three-phase motor, for the reasons mentioned above, is generally suitable underground, there is no reason, other than capital cost, why the various classes of machinery on the surface should not be driven by continuous current.

It may be urged that such a mixed system only introduces complications, but in some cases the advantages accruing would outweigh the disadvantages. Such machines as ventilating fans, air compressors, stone crushers, conveyors, screens, saw and mortar mill motors, locomotives, &c., can be driven better by continuous current motors because there is no limitation owing to a predetermined motor speed, and if speed regulation is required it can be arranged in an efficient and simple manner. In some cases continuous current is an advantage for lighting

The adoption of such a mixed system of course would involve a converter sub-station at each pit, or group of pits, whereas in the case of a purely alternating current supply a static sub-station only would be required if the current is generated or brought at a high voltage, or a switch-house only if the supply voltage is suitable for distribution.

A converter sub-station would, however, afford a ready means of raising the power-factor, and so increasing the value of the transmission line, and in this way might prove a very important asset.

It must be admitted that more attendance will be necessary in respect of the commutators on the continuous current plant, as, no matter how good the motors are, the commutators certainly require cleaning from time to time and need more attention than the slip rings on an alternating current motor.

In cases where no speed regulation is necessary, and the motor can be started on light load, a plain alternating current squirrel-cage motor is the most robust type that can be adopted, but its starting current and power-factor at low loads leave a great deal to be desired.

Due to the conditions underground, where rough work and makeshift arrangements, owing to emergencies, are from necessity so common, the safety and security of the system is not merely a question of a commutator more or less, as these are always, or should be, operating under the control of a competent attendant, but there is always present the risk of broken switch-boxes and damaged cables to guard against and to minimise.

Shocks.—The Home Office, in framing their Mines and Factory Rules, follow the Board of Trade and do not differentiate between alternating current and continuous current as regards precautions against shock.

The author's experience at equal voltages is that an alternating current shock and a continuous current arc are the more severe.

About five years ago, in connection with a Home Office inquiry as to the safe use of electricity in factories and workshops, the author assisted at some experiments made to determine the amount of current that could be carried by a person without severe discomfort, and then found that he could not grip hard with his hands two copper rods at a potential difference of 65 volts alternating and leave go as he felt a distinct contracting of the muscles The effect of 130 volts continuous current was practically the same, although the sensation was different; with continuous current the bars felt colder. The experiments were made to see how much current could be taken without discomfort. Two other persons began to curl up when 7 m-amps. passed, but the author could take 10 m.-amps. without any discomfort whatever. On repeating the experiment with continuous current, 25 m.-amps. was the limit that his two friends could stand; it seemed to curl them up more than 7 m.-amps. alternating. The author took 27 m.-amps. without the slightest sign of curling up, and could hold on to the contacts for an indefinite time.

The amount of current taken without discomfort depends considerably upon whether the experiment begins at a low value and the current is gradually raised, or whether the full value is put upon the experimenter suddenly.

In another set of experiments for which he arranged later, with four other men, both the pressure and current were observed simultaneously, the contacts, which were all bare copper, being held in the two hands as before mentioned. The results, which he contributed to the Inst. Min. Eng., Vol. XXXVII., p. 486, are shown plotted in Fig. A1. The lowest point of each curve marks the beginning of a sensation; the second indicates the current which was felt as disagreeable;

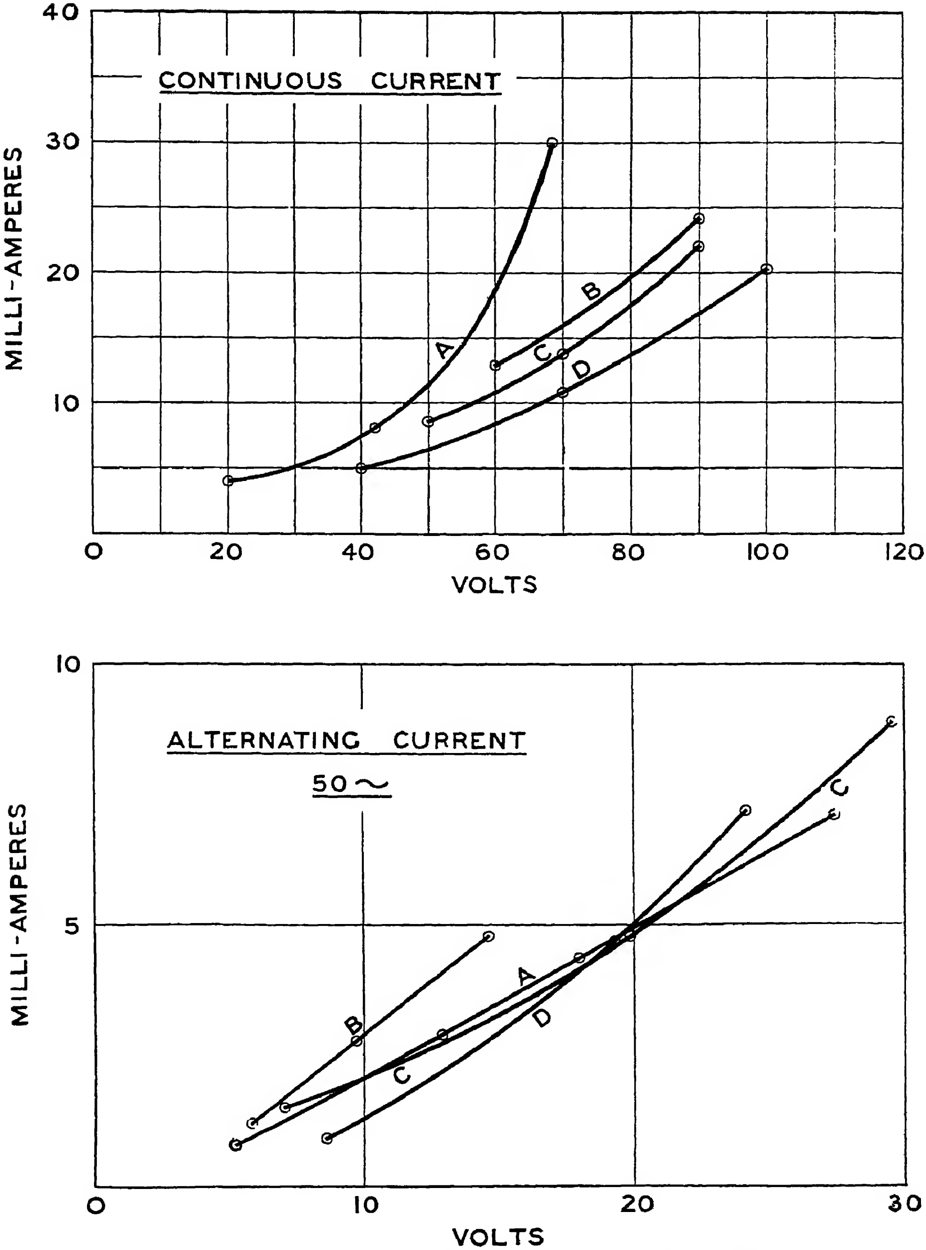

FIG. A1.—Effects of different voltages on the human body.

the third and highest being the limiting current which could be borne for some time.

The results appear to indicate that from 68 to 100 volts continuous and from 15 to 30 volts alternating current was as much as either of the four persons experimented upon could stand.

The effect on a person varies considerably; if a man is working in a damp atmosphere or is perspiring his body will make a much better contact than if his skin is dry. It was noted in all the experiments referred to that the mere fact of experimenting promoted perspiration, and all the seven experimenters appeared to get more sensitive in the course of the experiments.

These tests show that even ordinary house voltages may be dangerous if a person gets an unexpected shock from them, and proper distinction should be made between accidental contact and a firm contact. It is highly important to avoid a scare or to give people the idea that electricity is always dangerous, as when properly installed and handled it is probably the safest method of conveying energy.

An official report of the New South Wales Government states :—

> "Shocks from live wires intentionally left exposed occur most frequently in connection with low-pressure systems in consequence of the exaggerated ideas of the harmless nature of the shocks produced by them."

This is a perfectly true statement, and applies equally in this country. On the Continent it is the custom to label high-tension work with a plate bearing a lightning stroke or a skull and cross-bones in high relief, and everyone keeps clear of them, but low tension is handled with a familiarity which breeds contempt!

Generation of Electricity.—Electricity for mines is generated in various ways :—

(1) In the case of a colliery or mine having steam winding engines the exhaust steam from them, equalised by a heat accumulator plant, may be utilised on turbo-generating sets. It is not at all uncommon to find cases where all the remaining

machinery, both on the surface and underground, is driven by the energy thus recovered from the exhaust steam of winders, air-compressors, and possibly fan engines.

(2) In a colliery having coke oven plant the gases, which in the past were allowed to escape, are now subjected to a cleaning process and used to drive gas engine generating sets. Or, as an alternative, the gases can be burned under a boiler for raising steam which drives either turbo-generators or reciprocating engine sets. In either case the energy recovered in this way can be used for generating electricity, which can be distributed for driving the various scattered plant on the surface and underground

(3) In a metalliferous mine possessing its own blast furnaces, the gas which in the past was allowed to vitiate the surrounding atmosphere is now utilised in a similar way to the coke oven gas mentioned above.

(4) The case most frequently met, at least in colliery districts, is where the steam is raised from small coal or coal of little marketable value in a private generating station to supply the mine or group of mines.

The development of gas producers with mechanical grates which can handle low grade fuel is already beginning to attract attention, as by their use smudge and refuse coal can be economically gasified which could not be burned under a boiler without an undue amount of labour. This arrangement is advantageous and economical, as it sets free small coal for the market and usefully consumes fuel which is only a danger when thrown on to the rubbish tip.

In a metalliferous mine where fuel has to be bought oil engines may be used with advantage, either of the low-pressure Hornsby type, in which the oil is ignited by a hot bulb on the cylinder end, or of the high-pressure Diesel type, in which the oil is injected at a pressure of from 700–800 lbs. per square inch and is ignited by the temperature of the compressed air in the cylinder.

Whether power ought to be bought outside or produced on the premises must depend upon the local conditions. Capital ought to be expended where it will give the best return, and if power can be advantageously bought capital

may thereby be saved on a generating plant and laid out on current consuming apparatus and machinery which will give a better return on the investment.

The schedule of plant installed and user of electricity at the Ferndale Collieries may be useful, and is given in Table A5. It shows the advantage of concentrating the load on a power station instead of generating it at scattered points, and also shows the beneficial effect on the load-factor of electrifying fans and long hour-plant. Since the eight-hour Act came into operation and only one shift is worked, haulage and winding plant is only working regularly 48 hours a week, but has to be kept ready to run odd trips at any other time

TABLE A5.

PARTICULARS OF HORSE-POWER CONNECTED EXCLUDING STAND-BY PLANT, AND OF ANNUAL USER AT FERNDALE.

	h.p.		per cent
1 Haulages	3,300	=	46 60
2. Fans	1,360	=	19·20
3. Surface plant	810	=	11·40
4. Winder (on flywheel set) ..	700	=	9 88
5. Pumps	590	=	8·34
6. Surface lighting..	261	=	4·58
7. Pit bottom lighting	64		
	7,085	=	100 00

User, per annum .. .. 10,600,000 B.T.U.
Maximum demand (by switchboard instruments) .. 2,920 k.w.=3,920 h.p.
Maximum demand in percentage of power connected .. .. 55·3 per cent.
Load-factor .. .. .. 41·5 per cent.

Power Companies.—Power companies in England have not yet found a very ready market in the mining world. From figures lately quoted by the engineer the Lancashire Electric Power Company is at present supplying about 3,000 h.p., which will be shortly increased to about 4,000 h.p. The present annual consumption of the 3,000 h.p. is at the rate of

four million units per annum. This contrasts with the Ferndale private power station in South Wales, which supplies a group of eight pits.

There is a power company in South Wales which has 12,500 h.p. connected. The Newcastle district has three power companies which are supplying energy at the rate of over 55 million units per annum for colliery purposes. In the Clyde Valley district about 8,500 h.p is either connected or contracted for, and in Yorkshire there is a power company whose connections at present are about 4,000 h.p. with a 50 per cent. increase promised.

The use of electricity in the Westphalian Collieries is enormous and increasing rapidly. The nucleus of the public supply system was the station in Essen, which was started under private auspices, but is now the property of a company. Other works are now linked up to Essen, and there is a complete network for supply extending about 80 kilometres in one direction and 100 kilometres in the other direction. Ten stations belonging to the company and twelve stations belonging to private owners are linked up and supply into the same network. The supply is given to the different industries in the district. Figures as to the supply to mines have been published by Dr. Jungst in "Gluckauf," December, 1911, giving the output of electric power for the coal mines in the Ruhr district :—

1906	.. ..	58,000,000	k.w. hours.
1907	.. ..	107,000,000	,, ,,
1908	.. ..	171,000,000	,, ,,
1909	.. ..	256,000,000	,, ,,
1910	.. ..	461,600,000	,, ,,

Out of the total production in 1910 about 402,000,000 k.w. hours were used for the collieries. The iron and steel works, some of which are run in connection with the collieries, are also large consumers and producers. The production is chiefly obtained from blast furnace gases and coke ovens, the surplus energy being supplied into the public mains with give-and-take contracts between the public supply company and the private owners.

Choice of Frequency.—For mining work 50 cycles is preferable to 25 cycles, as it gives more latitude in the choice of speed. While 25 cycles gives a choice of sixteen speeds between 1,500 and 94 r p.m., 50 cycles gives the same choice over a range from 3,000 to 187·5. This high speed is more valuable than the very low one.

High lift centrifugal pumps call for very high speeds, such as 3,000 r p m , consequently, as high speed and efficiency are inseparable for this type of machine, their use is frequently debarred on a 25-cycle system unless recourse be had to belt or rope drive.

CHAPTER II

CABLES

Lighting.—Lighting on the surface may be arranged on the same lines as are generally followed.

For underground lighting separate insulated wires attached to insulators are preferable to wires drawn into iron tubing, as, owing to the frequent movement of the ground, which bends the tubing, and condensation in the tubing, it is very difficult to maintain a satisfactory insulation test. Where necessary to protect them from mechanical injury they can be armoured or efficiently guarded without drawing them into metallic tubing.

Classes of Cables.—Mining cables have to be designed to meet the special conditions which arise in connection with their use :—

(1) On the surface ;
(2) In the shaft ;
(3) Along the roadways or in-bye ;
(4) For flexible connections to portable machines, such as coal-cutters and drills.

The cables available are insulated with :—

(*a*) Paper, lead covered ;
(*b*) Paper, leadless ;
(*c*) Bitumen, dialite, or diatrine, which are all three bituminous compounds of a more or less secret nature.
(*d*) Indiarubber.

Any or all of these four classes may be protected by an armouring of steel ribbon or wire in single or double layers, or lock-coil wire.

Bare conductors underground except the outer conductor of a concentric system are prohibited by Special Rule 12 (a) in this country, although, by special consent obtained from the

Secretary of State, locomotives on the trolley system may be used under Special Rule 19 (b) in mines other than coal mines.

Due to the greater danger of getting water into the core of a cable by capillary attraction in mining work, systems of solid filling have been brought out to prevent this defect. A slight fault in the insulation of a cable which admits water to the core may, without the solid filling, lead to the deterioration of a long length of cable, so that the improvement, although it appears to be a small detail, is an important one.

(*a*) *Paper, Lead Covered.*—The high reputation of paper lead-covered cable as used in other industries has led to its being used in mines without proper consideration as to whether the usual lead covering is suitable or not.

The use of lead covering has not been altogether successful, although in many cases it has given the greatest satisfaction. Pit water is frequently very corrosive, and its effect on the lead covering is accentuated by any leakage currents.

(*b*) *Paper, Leadless.*—This risk of corrosion is now overcome by the paper "leadless" cables which are offered by several makers, in which the lead covering is replaced by a covering of bitumen. A cable of this description possesses most of the advantages of a paper lead-covered cable, but it does not get over the necessity of employing a high class workman to make proper joints on a paper insulated conductor. The bitumen covering is also more flexible than lead covering, but the quality of the bitumen used is very important, as it must be tough without being brittle.

(*c*) *Bitumen Cables.*—These have perhaps been used more extensively than any other type. The best are insulated throughout with bitumen, and in the case of multi-core cables are packed with bitumen and not with yarn or any other hygroscopic material. Where armour is necessary the bitumen is protected by a layer of impregnated yarn, which prevents the edges of the armour cutting into the insulation, the armour in its turn being protected from rust by a further serving of impregnated yarn.

Where bitumen cables require dressing a paint of bitumen or Stockholm tar may be used.

The jointing of bitumen cables is skilled work and needs care, but it is not such highly skilled work as the jointing of paper cables.

Bitumen may be safely employed for pressures up to 3,000 or 5,000 volts ; for high pressures paper is generally employed on the score of space occupied and convenience.

The danger of decentralisation, which has occurred with some bitumen insulated cables, may be practically overcome if the core is covered with a thin layer of jute, or paper, before the bitumen is put on.

It is not, however, safe to use a bitumen covered cable in all cases, as alkaline waters are apt to attack it, particularly if they are warm. The worst effect of the alkaline or acid pit waters is not so much that they act chemically upon the coverings of the cable, but that slight leakage is always apt to occur, and this leakage is considerably aggravated by the electrolytic quality of the water.

As regards the relative advantages of paper insulation and bitumen, the author has been responsible for many miles of each working in shafts and underground for several years past ; the performance of each has been excellent with an entire freedom from trouble, so that he is not prepared to say there is a best. Each is excellent when properly handled. Where highly skilled labour is not available bitumen is the safer to use ; for high-tension work skilled labour is essential from other considerations than cable jointing, so that the requirement of skilled labour is naturally, or ought to be, met, otherwise the use of high tension is courting disaster and may do an injustice to the mining industry.

(*d*) *Indiarubber* has been largely employed as an insulator for small wires, but its expense has limited its adoption for cables since the exploitation of bitumen and kindred substances. It is still used for connections when its greater flexibility is important.

Protection.—The new Special Rules proposed in 1911 provided (Rule 12c) that either concentric cables shall be used or two-core or multi-core cables protected by a metallic covering

(i.) where the pressure exceeds 250 volts ;

(ii.) the roadway conveying the cables is used for mechanical haulage; and
(iii.) there may be risk of igniting gas, coal dust, or other inflammable material.

Armouring.—This Rule practically meant the general employment of armoured cable or protective metal barrel, barred the use of single cables, and raised one of the most debated points in the transmission or use of electricity underground.

Many managers of mines claim long years of satisfactory service for unarmoured systems of continuous current supply and stoutly resist any attempt to change them, the reason being chiefly the cost of the work, which they do not feel is justified. For new work the difference between armoured cable and unarmoured, by the time it is laid, is small, but the cost of tearing out an existing satisfactory system appeals to nobody who has to provide the money!

To meet the objections raised the Special Rules were revised, and, as proposed in February, 1912, the Rules applying to concentric two-core and multi-core cables stand, and the same rule (12c) now admits single-core cables protected by a metallic covering which contains all the conductors of the circuit for use under any of the three conditions referred to. An exception has also been made in favour of continuous current as follows:—

"Provided that if the medium pressure direct current system is used, (i.) two single-core cables protected by metallic coverings may be used for any circuit if the said metallic coverings are bonded together by earth conductors so placed that the distance between any two consecutive bonds is not greater than 100 ft. measured along either cable, and (ii.) two single-core cables covered with insulating material efficiently protected otherwise than by a metallic covering may be used in gate roads (except in gate roads which are also used for mechanical haulage, or where there may be risk of igniting gas, coal dust, or other inflammable material) for the purpose of supplying portable apparatus."

While most people will admit that an armoured system properly laid and maintained is the safest of all systems *quâ*

shock, those with practical experience of underground working must admit—

(1) That shocks have occurred from armoured systems badly done or allowed to get into a bad state of repair ;

(2) That a higher standard of labour is required for the laying and maintenance of them ; and

(3) The risk of interruption on an armoured system is greater than on an unarmoured system, owing to the absence of the protective devices operating automatic switches on the latter.

On the first point the badly executed work is often the key to the situation, and the whole claim may be classed as a concession to bad work.

That there is plenty of bad work seems evident from the Report of H.M Chief Inspector for 1910, above referred to, where in Table 44 he gives particulars of accidents and an analysis of the systems on which they occurred as follows :—

Fatal shocks from armoured cables	1
,, ,, ,, unarmoured cables	5
,, ,, ,, concentric cables	0
Total..	6

The evidence is greatly strengthened if the record of the last five years be taken into account which he gives in Table 45.

Fatal shocks from armoured cables (1905-10) ..	3
,, ,, ,, unarmoured cables (1905-10)	20
,, ,, ,, concentric cables (1905-10) ..	2
Total..	25

On the second point the higher standard of labour means better training and better pay, but not necessarily increased cost as low-priced labour is not always the cheapest.

On the third point leakage indicators are available which will show a leak before the current is large enough to work the protective devices.

Where a protective system is to be adopted the armouring of

the cable is a practical necessity, and certainly nothing would appear to give greater safety than a thoroughly well-made and well-maintained armoured system, but it must be admitted that higher skill is called for both in the laying and the subsequent supervision of armoured cable than for unarmoured.

It is more difficult to localise a leak on an armoured cable than on an unarmoured cable, as the leak on the armoured cable will show all over the system, so that disconnection and local testing is necessary.

The leak on an unarmoured cable is purely local ; a damaged place which did not cause an actual leak might remain undetected until some person got a shock by contact with it.

An armoured system without protective devices has the elements of danger in the event of the earth connection being broken, as, given that the armouring is completely bonded, a leak on to the armour makes the whole of the armour alive, so that a shock might be obtained anywhere. It is therefore better to "earth" the armour at all possible places, although one spot should be looked upon as the main earth.

Armoured cables are certainly less liable to damage if properly installed than unarmoured cables, but the efficient and safe working of the system depends on their earth connection and bonding being kept in a proper state of repair. The armour itself is of valuable assistance as a means of earthing switch-boxes, motor-frames, &c., which must be done, and in the absence of armour a special cable or core has to be provided for the earth circuit. In the author's opinion a substantial armouring is preferable, and the cost of maintenance of a properly laid out and executed system is negligible.

Concentric cables, with the outer conductor used as the return and earthed, are in themselves good, but they have suffered from users who have been careless in extending the system by single cables and so have broken the concentric arrangement and turned what was an important element of safety into a danger.

Cable Laying.—In laying cables above ground for mines the usual methods are adopted, but two points require special

attention. Owing to the continual movements underground, consequent on the removal of the mineral, subsidences on the surface are apt to occur; provision must therefore be made to accommodate such movements considerably in excess of the usual movements due to changes in temperature which occur during normal operating conditions. Cables are sometimes "snaked" or staggered in the trench, when armoured, and laid direct in the ground, this method is found to be quite effective. Cases

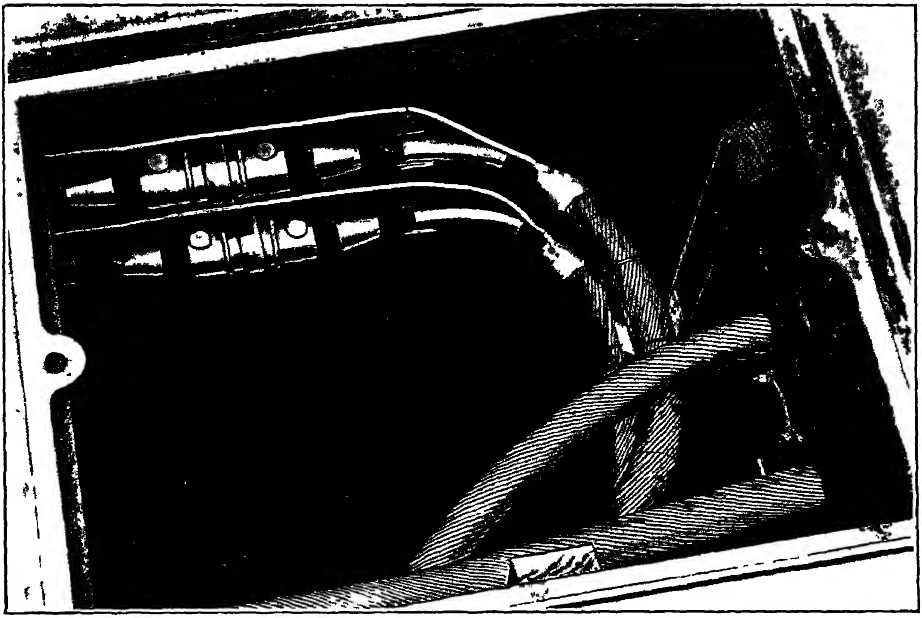

FIG B1 —Looping of cables round pits

are on record of cables which have been laid on one side of a road and in a few years have moved to the other side.

In the case of a very bad subsidence area in the Lancashire colliery district, Messrs. Glover used Mannesman tubes with caulked joints into which wire armoured cables were drawn. Brick-pits were built at intervals on the tubing in which the cables were looped round (Fig. B1) in order to allow plenty of play. This method of laying has been quite effective as the cables have not given the slightest trouble.

Messrs. Callender make a flexible joint-box specially designed

to prevent trouble from expansion or contraction. Vernier has also arranged an expansion joint in which the inner wires of the conductor slide in a tubular guide while the outer wires are bridged with flexible copper braid. (*Jour. Inst. Elec. Eng.*, Vol. XLVII., p. 329.) This relieves the strain at the joint, but does not obviate the necessity for special care between the joints.

As pit yards are made up so largely of ashes and in coal mines of material liable to spontaneous combustion, the nature of the soil must be considered. An overhead line may be preferable but impossible owing to obstructions, and then the best must be done to make the cable trench safe. The author has used brick walling and brick trenches to keep heat off the cables, and in some cases clay has been carted to the trenches and well punned in round armoured cables to protect them from the effects of ashes and organic impurities, with quite satisfactory results.

Shaft Cables.—The shaft cable is the most important part of the installation, as a fault on a shaft cable is difficult to get at, and may interrupt the working of the pit while it is being attended to. For this reason, in important pits duplicate shaft cables should always be employed.

It is better to put cables in a down-cast shaft, *i e*, in the shaft by which the air enters the mine, than in the shaft through which the air leaves the mine, as the down-cast shaft is cooler and less humid than the up-cast shaft.

In fact, local conditions have to be considered in every case, and no fixed rules can be laid down as to what class of cables ought to be employed or where they should be fixed. Every case must be dealt with on its merits after consultation with the management of the mine.

Cables up to 1,000 ft. or 1,100 ft. in length have been suspended from the top of a shaft, without any intermediate attachments. It is seldom that this method of fixing shaft cables need be employed, and it has little to commend it, except in shallow pits.

One of the best types of shaft cable is the lock-coil armoured cable, as such armour is a better protection than any other

type, and is stronger. The peculiar section of the armouring makes the repair of such a cable more difficult than when round wires are employed.

If a steel wire armouring is used for shaft cables, it should be in double layers laid on in reverse directions for strength, and also to prevent the tendency to untwist. This tendency is absent in lock-coil armouring. Such cables may be supported in the shaft by cleating. Steel tape armouring should not be used for shaft cables.

Cleats.—Cleats of elm or pitch pine, 2 ft to 3 ft long, bored to the diameter of the cable, and then cut with a saw, and the sharp edge removed, give a better all-round grip on a cable than the V-shaped cleats which have sometimes been employed. The two halves of a cleat are bolted together by $\frac{5}{8}$-in or $\frac{3}{4}$-in. bolts, and they are attached at suitable positions in the shaft. In some cases they may be secured to the buntons, or cross beams, in which case the cables in a winding shaft should be at the back of the bunton, and not on the front or cage side. Cleats may also be attached to the walls of a brick shaft by Lewis bolts or to short lengths of girder let into the brickwork. When the shaft is tubbed with iron casing the cleats may be bolted thereto.

Another method of securing the cleats is to suspend them by chains so that slight movement is allowed ; this accommodates expansion due to temperature changes and takes the vibration off the ends of the cleats, where it is sometimes concentrated with ill effects on the insulation. It is prudent to provide auxiliary anchors to take the strain due to a broken chain. The tops of the cleats should be chamfered off to prevent the lodgment of falling material, and are better protected with a wrought-iron hood, although such extra protection, unless put up thoroughly well and strong, is objectionable in that it may become dislodged by falling material and so add to the danger of persons travelling or working in the shaft.

Fig. B2 shows the single suspensions for paper armoured cables supplied by Messrs. Glover & Co., and fixed by the Hulton Colliery Company at their Pretoria pit. In this connection it is noteworthy that these cables came through the

recent disaster unscathed, in spite of the fact that many hundred tons of roof collapsed upon them.

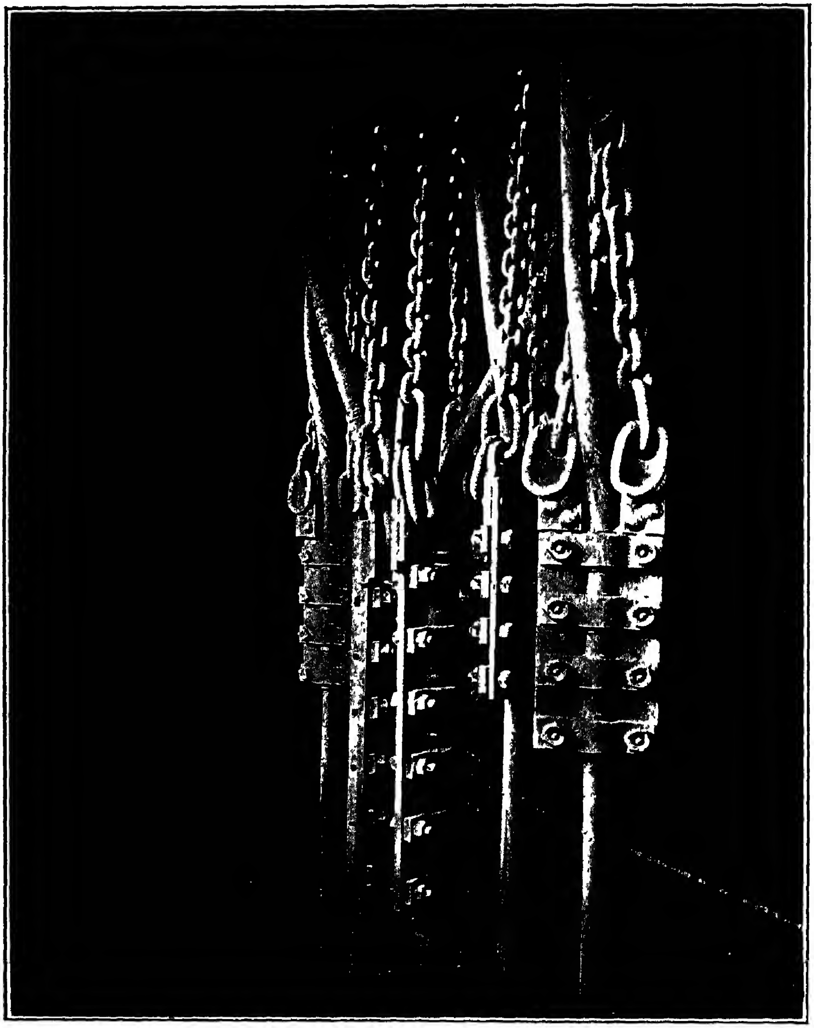

Fig. B2.—Shaft suspension of paper armoured cables.

Casing.—When unarmoured shaft cables are used they are generally boxed in with a creosoted heavy timber grooved casing, the grooves being such that the cable can just be driven into it a snug fit, and the friction along its whole length

is then sufficient to keep it in place. The covers of the casings must be securely fixed and made waterproof with tar or bitumen paint. In wet shafts the less timber used the better.

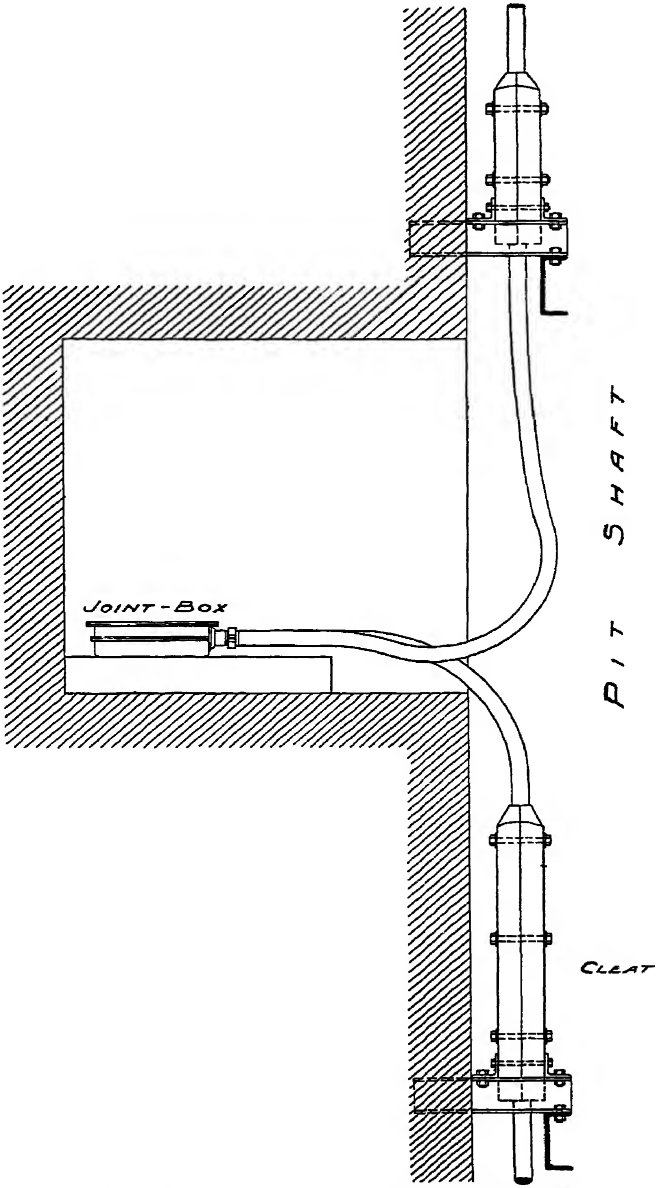

FIG. B3.—Joint-box in lodge in pit-shaft.

Fixing.—The shaft cable should, if possible, be arranged without joints, as no joints are admissible in the shaft, and when any are necessary, if no lodge room is available, pockets or arches should be formed in the side of the shaft in which the joints can be made (Fig. B3). The joint-boxes must be properly anchored, and the cable should be carried below the joint-box and then raised slightly into it, so that any water running down the cable drips off the bend instead of flowing over and perhaps into the joint-box.

The method of lowering the cable into the shaft and fixing it there must depend on the local conditions. When the cages are steadied by rope guides the shafts are less encumbered with buntons than where rail guides are employed, as the ropes are kept taut by weights suspended to them in the sump, while rail guides have to be supported on framework and buntons are placed at frequent intervals.

The position selected for the cable must be as much out of the way of cages or falling material as possible. In cases where the walls are bad, space necessary for repairs must be allowed between the cables and the wall, and in any case the cleats should project so as to allow sufficient clearance between the wall and the cables to prevent the lodgment of dirt or water.

The temperature of the shaft must be considered in all cases, as if a cold cable is cleated up in a warm shaft the subsequent expansion of the cable may be very detrimental, so that it must be allowed to attain the shaft temperature before it is permanently fixed. Half a day to a day is a fair allowance.

The easiest method of fixing is when the cable can be cleated on the outer face of the buntons, or on the unobstructed side of a shaft. The drum is then slung in or under the cage on temporary trunnions with an efficient brake to control the amount of slack paid off. The cable is paid off the drum, temporary lashings being put on as required to hold the cable in place until it is permanently cleated from the top downwards. The arrangements must be very carefully made and no "chances" taken, as if there is a hitch either in the drum or cage it is very difficult to rectify matters with the cage half-

way down a shaft. Fig. B4 shows the operation as carried out by Messrs. Callender at the Sneyd Collieries.

A locomotive may be used to lower a cable down a shaft, but the method is not very convenient. It must first be run out full length so that the loco can be attached to the end of

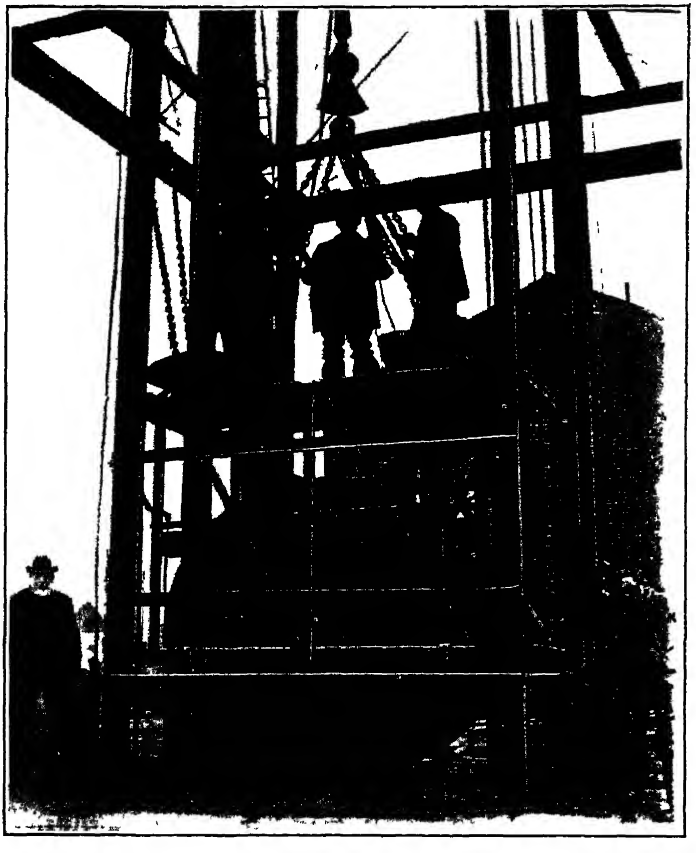

FIG. B4 —Loweiing Callender's shaft cable

it, and then it must be handed down the shaft over a big pulley, to prevent it being bent to a small radius, until the weight of the suspended part is sufficient to overcome the friction, when the loco merely acts as a brake. In this case the cable during fixing supports its own weight.

Another method adopted is to lash the cable at suitable

intervals to a steel rope, lowering them together gradually down the shaft The cable can be permanently cleated as soon as the normal temperature is arrived at or exigencies of the shaft work permit; meantime it takes no harm, if the lashings do not slip, to prevent which they must be carefully made with cotton or other soft rope

Sometimes the full drum can be lowered to the bottom of the shaft and the cable hoisted up the shaft by a rope made fast to its end This again means that the cable must be strong enough to carry its own weight and the additional strain which may accidentally be put upon it in handling, so the method can only be safely adopted with armoured cables, and care must be taken that a good swivel hook on the rope, or preferably a lock-coil rope, is used for hoisting to prevent twisting of the cable.

There is less risk of the cable running wild when it is being hoisted by a proved tackle than when it is being lowered and the paying off only controlled by a provisional brake, hence this method of handling has much to recommend it.

In every winding shaft the winding engine is available for hoisting or lowering, and in most mines a strong winch, which is used during repairs, &c., is also available as an alternative.

In every case arrangements must be carefully planned and carried out, so that the minimum interference with the working of the pit occurs not only in fixing, but in the subsequent working of the cables

The less time that a cable, which is not intended to carry its own weight, is left suspended by the armour the better. The danger is in stretching, not in breaking, the armour, as if it stretches the cable will be deteriorated, if not destroyed.

The longest length of shaft cable that the author has handled is 200 yards, weighing about $2\frac{1}{4}$ tons

The longest that he has a record of is a 380-yard length of three-core 0·4 sq. in. 500 volt vulcanised Bitumen, double wire armoured cable, supplied by Messrs W. T Henley & Co., for the Dechmont Colliery. The overall diameter of the cable was $3\frac{1}{2}$ in., and the breaking strain 50 tons The weight of the cable and the drum, 9 ft. diameter over flanges, by 5 ft. wide on which it was delivered, was $8\frac{1}{2}$ tons. This cable was sus-

pended in the shaft during erection and then cleated into its permanent position.

Sinking Drum.—When a shaft is being sunk the cable for lighting or shot-firing is generally wound on a special drum and paid out as required. Fig B5 shows such a drum made by Messrs Glover & Co.; the slip-rings through which the electrical connection to the end of the cable is made will be seen

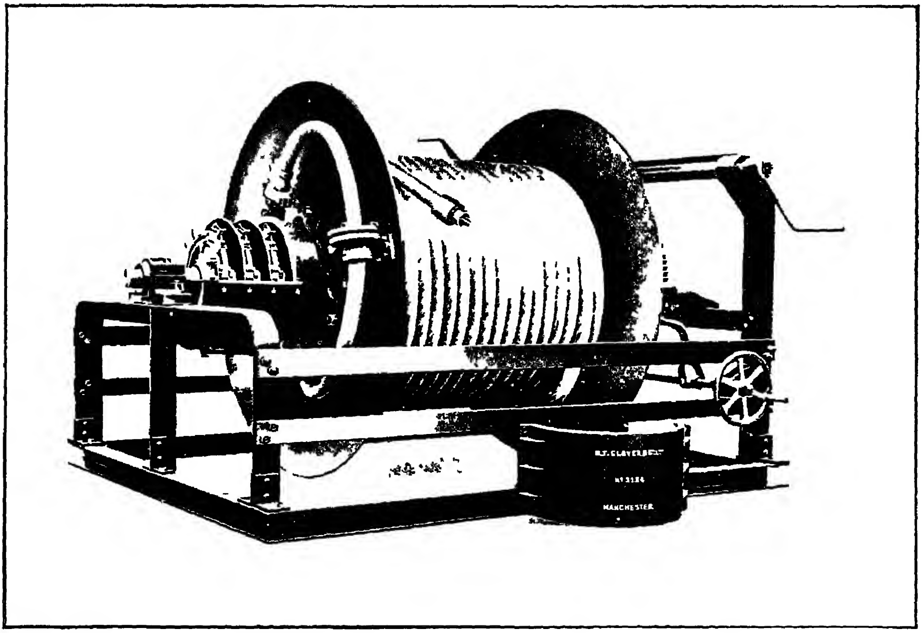

Fig B5 —Glover's sinking cable drum

on the spindle. The cable sockets for the incoming cables are below the slip-rings, and a clamp is provided to secure the cable and relieve the sockets from strain

Shaft-bottom Switches.—It is good practice to put a switch at the bottom of the shaft to cut off the current from the underground cables In a large mine this switch becomes a distributing centre whence the various cables going into the workings radiate. When two shaft cables are used busbars and

switches should form part of the equipment, and be arranged as simply and securely against the risk of shock and fire as possible. Unit oil switches in cast or wrought iron casings are now available for such work. Their cost is very little greater than that of open switches, and they are well worth the expenditure, even in cases where there is no danger from gas or dust.

In-bye Cables.—The road-ways under ground vary enormously, not only in size, but in quality. Some road-ways are bricked or stone-walled in a fashion that a railway engineer would consider high-class work for a tunnel, and they are large enough to take a full sized railway coach. In other cases the road-ways are hewn out of rock or coal, the roof and sides being supported, or not, as may be necessary, by timber or steel. The timbers in some cases having to be quite close together to prevent the ground running through ; in other cases they may be spaced widely apart. In some mines the floor, sides and roof are all good , in others they are constantly moving, so that repairs are going on continually. The repairing gangs have been apt to consider that the cable, which looks so innocent, is quite safe and can be treated like a rope, with impunity ; it is often, therefore, thrown anywhere instead of being carefully handled and covered up to prevent injury

Where a road is used for haulage the moving character of the ground often renders the proper maintenance of the lines difficult, so that the trains of wagons may often be derailed. It is therefore important that the cable should be so placed that there is the least possible risk of injury during such derailment. If the derailment takes place on an incline, or if a shackle breaks and a journey or train runs wild, the wagons get piled up so that the chance of injuring the cables is increased.

Armouring.—These considerations point to the frequent advisability for mechanical reasons of using armoured cable.

If a cable is laid on the ground, and a heavy stone falls with a sharp corner on to the cable, a short circuit may occur, but special tests that have been made with negative results, and also years of practical working, have shown that the danger is

remote The security of the cable generally depends in these cases upon its laying on a soft yielding bed, as of course if it were laying on a hard rock like an anvil, the chance of injuring it would be greater.

Armoured paper insulated cables have frequently been badly bruised by falls of rock without any fall in their insulation resistance occurring.

Steel ribbon is generally used. For the sake of flexibility it has to be wound on so that it leaves an open space at each convolution , to cover these spaces an outer layer is necessary, which is laid on at half-a-pitch difference. If the outer layer were laid on in the reverse direction the cable would be too stiff for convenient handling.

If greater flexibility is required steel wire armour is used—in one layer for small cables, and two layers, laid on in reverse direction, for larger sizes or where greater strength is necessary.

Fixing.—Cables should preferably be taken in-bye along the fresh air-ways, as not only is the air more free from gas, but it is less humid. At the same time it must be remembered that a fire which occurs in the fresh air-ways may fill the workings with smoke and suffocate the men, while a fire in a return air could only affect part of the workings. Hence the greatest possible care should be exercised in all the cable-laying and maintenance operations, and, although more freedom is allowed for working in fresh air-ways than in the returns, advantage must not be taken of the greater freedom which might admit carelessness.

Temperatures under ground are sometimes high, but not dangerously so as regards the cable, as where men are working the temperature must be kept considerably lower than any temperature which is injurious to dielectrics. More heat risks are run in the yards on the surface than under ground so long as steam pipes are avoided.

Cables are not often laid directly in the ground along the roads underground owing to the shifting and squeezing that is constantly going on. If such a situation is chosen slack must be allowed by snaking the cable and special care taken to prevent joints being drawn apart, as mentioned above in connection with surface work.

Pipes for air compressors were always laid along the roads, and frequently became buried by falling material ; when out of sight they were out of mind, and leakage was not evident except in wet roads where " geysers " formed. Such conditions are not permissible for cables.

The ideal site is where the cables are always in sight and, while out of the way, can be easily got at for inspection or overhauling.

Special protective precautions must be taken when the cables are run near stables or where horses are likely to stand, as they have an awkward knack of biting them. This propensity has caused the death of several horses. If the cables cannot be put out of reach of the horse they should have extra metallic protection.

When the electrification of the Ferndale pits was in progress, to the author's specification, the management so thoroughly appreciated the importance of properly protecting the cables that when any new walling was in hand ledges were formed in the brickwork, into which the cables could be laid. The result has been very satisfactory and the expense justified The cable-laying is of the simplest character, and the ledges have afforded excellent and secure runs for one, two, or three cables, according to requirements.

If a roadway is large enough to allow a drum mounted to revolve on an improvised truck to be run along it, the cable may easily be paid off and lifted into its permanent position without risk of damage. Every care must be taken that a cable is not violently dragged over the ground and round corners ; it must be carefully handled by an adequate gang ; it is better to postpone laying rather than run the risk of damaging a cable when working short-handed. When proper care is taken to avoid injury during laying, any subsequent faults, except in the case of mechanical damage, will most probably occur at the joints and ends. It is often difficult to get joints made and ends properly finished in broad daylight ; underground the difficulty is far greater, so that closer inspection and care are necessary.

Improvised branch and trifurcating boxes are to be avoided ; proper fittings, standardised by the leading makers, are obtainable and cheaper than make-shifts.

Temporary wiring and connections have an unfortunate way of becoming permanent, and are a source of weakness and danger that must not be admitted.

All branch leads and tail ends require special protection to prevent chafing or mechanical injury.

Suspenders.—To prevent a fall of ground putting a strain on the cables they must be suspended by readily breakable material. Impregnated spun yarn slings have been generally used as they are always available. Various types of suspenders so designed that if an undue strain comes upon them they open and allow the cable to slip out, have been used.

In Glover's impregnated woven canvas sling the eye and collar are of malleable galvanised steel ; the lower part of the eye is wedge-shaped, and automatically grips the ends of the sling between itself and the collar. In the event of strain the wire hooks open out and allow the suspenders to fall.

Leather thongs have been employed, but their use cannot be recommended in damp situations owing to the action of mildew on the leather.

Hoop-iron suspenders have also been employed, and are very serviceable where free from rust.

If the cable is suspended in this way the danger of a fall of the roof injuring it is remote, as a well-made armoured cable will stand a considerable amount of ill-treatment before the armour is driven on to the conductors.

On a dip or incline ordinary leather or similar suspenders are insufficient to take the pull of the cable, which must be suitably anchored at intervals.

An unarmoured cable requires a wider sling than an armoured cable as it is softer, and in a warm place a thin sling may gradually sink into bitumen or similar insulation. Impregnated canvas slings, provided with brass eyelets through which the suspending yarn or hook can be passed, serve the purpose admirably, and are not so easily lost during road repairs as small slings.

Joint-boxes.—Joint-boxes should not be placed directly on the ground but on seatings with an easy run-off each way to take the weight of the cable off the joints.

Where sweated joints cannot be made screwed joints of various types may be employed, but they must be heavy and not of a type likely to work loose or pull out.

Fig. B6 shows Glover's mechanical connector, in which the central cone is split longitudinally in halves. The cone is pushed into the cable between the core and the outer wires of the strand, which are then pressed down into the cone by the tightening nut and glands.

Bonding of armour, lead, or earth wires to and across all boxes must receive special attention.

It is a mistake to bond boxes on the lid only, as when the lid is removed the continuity of the earth circuit is broken. The body of the box and its lid must both be properly bonded The

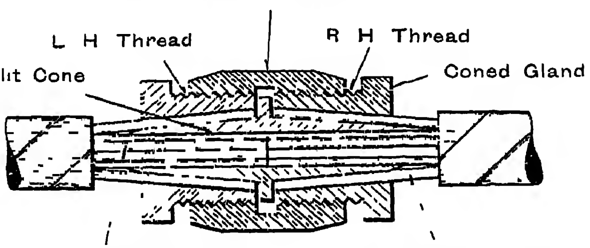

FIG B6 —Glover's mechanical connector for conductors

armour should be bonded across the box independently by a short length of cable attached to the armouring or sheathing by screwed, and, where possible, sweated clamps. This ensures continuity in the event of the box being taken off when the cable is alive, as sometimes happens on low-pressure work. High-pressure work must be made dead before boxes are worked upon Medium and low-pressure live cables may safely be worked upon under ground, as they are on the surface, if adequate precautions are taken ; so the continuity of the earth connection is necessary for the protection of other persons in the mine, not for those who are working on the box. Fig. B7 shows Messrs. W. T. Glover & Co.'s latest type of bonding and jointing box. The cables entering this joint are paper-lead-covered E.H.T. bitumen sheathed and steel wire armoured. Not only is the inner lead sheathing hermetically sealed and

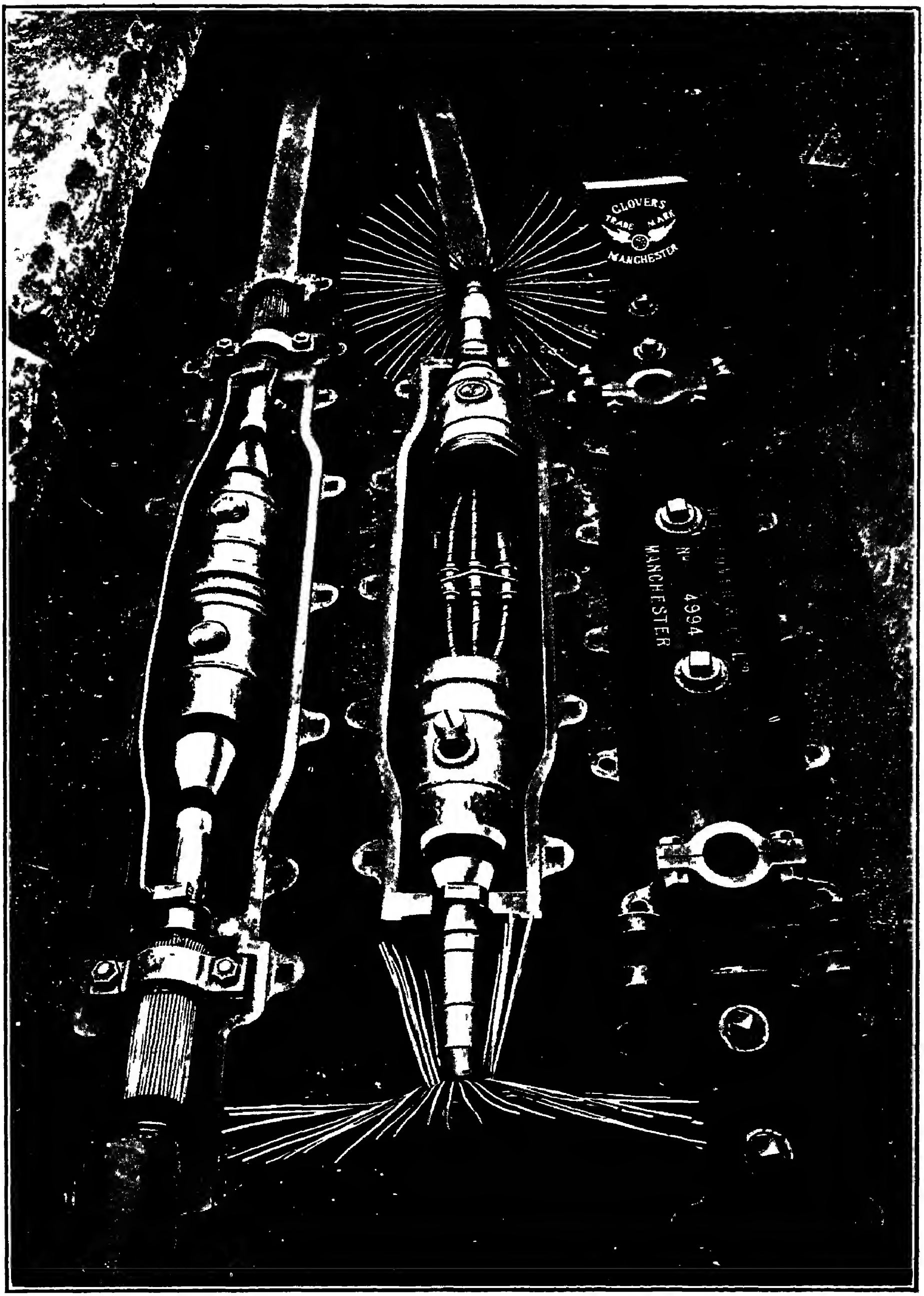

FIG B7.—Bonding for continuity by means of cones and collars.

made continuous by the use of a patent cast-lead sleeve, but the armour is also bonded for continuity and earthed on to the box in the manner clearly shown in the figure. That portion of the cable partially weakened by the necessary bending back of the armour is made good by being enclosed in an additional box attached to either end of the main fittings, which is, of course, filled up solid with compound.

Earthing should form part of the worked out scheme and not be left to the caprice of the jointer.

In all rules reference is made to earthing, but they do not define the exact method by which it should be accomplished, each case must be dealt with on its merits Mr. Nelson, H.M. Electrical Inspector of Mines (Trans. Inst. Min. Eng, Vol XXXVII, p. 481), describes earth plates and earthing in a way which is worth repeating —

"Unless the conditions are altogether abnormal, a copper plate of 16 standard wire gauge, about 3 ft by 6 ft. in area, buried in a damp place or below permanent moisture level, with 2 ft of crushed coke both under and over it, should make a sufficient earth for an ordinary colliery installation. Two such earth plates are recommended to make sure that one at least is fulfilling its duty Should the ground be everywhere dry, the neighbourhood of an earth-plate must be frequently and freely watered. Copper plates are preferred to cast-iron plates because of possible difficulty from corrosion Main earth connections should be of copper and have a section of not less than 0·25 sq. in If it is a bar measuring 1 in. by ¼ in., it may be connected to the earth-plate by sweating and rivetting an 18 in. length to the copper plate If a wire, it should be sweated to a lug of ample dimensions, itself in turn provided with a flat base measuring not less than 3 by 6 in. to be first carefully cleaned before being securely rivetted and soldered to the plate. The use of a pipe-line or of anything other than a proper earth-plate is not in general recommended; the best system consists in first sinking good earth-plates, and afterwards in taking such precautions as may be found necessary in practice to keep them in condition. No earth connection of any kind should be less than 7/20 copper wire or

equivalent section; and the wire should never be vaguely wrapped round the object to be earthed, but always provided with a proper terminal lug"

The Regulations of the Board of Trade as to Electric Power on Tramways and Light Railways (April, 1910) are also useful on this point. No. 5 (*a*) provides for two separate earth connections which shall be placed not less than 20 yards apart. And No. 5 (*b*) provides that these connections "shall be constructed, laid and maintained so as to secure good electrical contact with the general mass of earth, and so that if possible an electromotive force not exceeding four volts shall suffice to produce a current of at least two amperes from one earth connection to the other through the earth, and a test shall be made once in every month to ascertain whether this requirement is complied with."

Water pipes should not be solely depended upon, although they form a good and useful auxiliary earth circuit. The insertion joints between flanges may be looked upon as insulators, but their effect is cancelled by the bolts

Pipes driven into the ground and connected in parallel are sometimes preferred and form an excellent substitute for the more common form of earth plate.

The best size of the earth connection has often been discussed, it certainly must be large enough to carry the overload current of the machine or cable to which it is attached without risk of fusing, and must be strong enough to avoid risk of mechanical injury, otherwise it may be, like so many electrical contrivances, good enough electrically, but mechanically bad, and so unsuitable for the purpose intended.

Sometimes an old haulage rope is used as an earth connection where armouring is not available. In such a case special care must be taken to clean the ends to ensure good electrical contact.

The earth circuit and connections should be tested constantly and kept in good order. They must be looked upon as fire-escapes or engines which may seldom be used, but when they are wanted they are wanted badly!

Distribution.—Clause 11 of Appendix "A" of the Report issued by the Electricity in Mines Departmental Committee

(1909) reads as follows :—" (*a*) Properly constructed switch-gear for cutting off the supply of current to the mine shall be provided at the surface of the mine within 200 yards measured by road or path from the pit-shaft or drift containing the cables, and during the time any cable is live a person authorised to operate the said switch-gear shall be available within easy reach thereof" This is practically one of the 1904 Rules, but has been revised during the late discussion, and the 200-yard limit is now deleted. The principle, however, still stands ; consequently a sub-station is generally erected within the specified distance, or if no transforming or rotating machinery is necessary the switch-gear may be installed in the basement or other available room of one of the existing buildings. This sub-station or switch-house is the distributing centre whence all underground and surface machinery is controlled.

The distribution on the surface for all large motors, such as those for winders, fans, or compressors, is generally at high pressure, each large machine having its own supply cable and switch-box in the sub-station. For the smaller auxiliary machinery the pressure is stepped down again to medium pressure. These small motors are usually all connected on to one distributor.

As regards the supply for the underground machinery, generally two cables, each sufficiently large to cope with the maximum load without excessive pressure drop, are installed. These cables are usually taken down one of the shafts to a switch-house situated near the pit bottom. Any pumps situated in the shaft lodges are connected to these cables by means of change-over switches, so that they can be worked from either of them. From the switch-house at the pit bottom all the haulages and pumps are supplied, each large machine having its own switch-box and its own cable.

Rule No. 16 in the 1904 Code called for a plan showing the position of all permanent electrical machinery and cables in the mine.

Rule No. 3 of the new Code calls for a proper plan on the same scale as that kept at the mine in fulfilment of the requirements of the Coal Mines Regulation Act, 1887, showing the position

of all fixed apparatus in the mine other than cables, telephones and signalling apparatus.

A great deal of money has been muddled away owing to

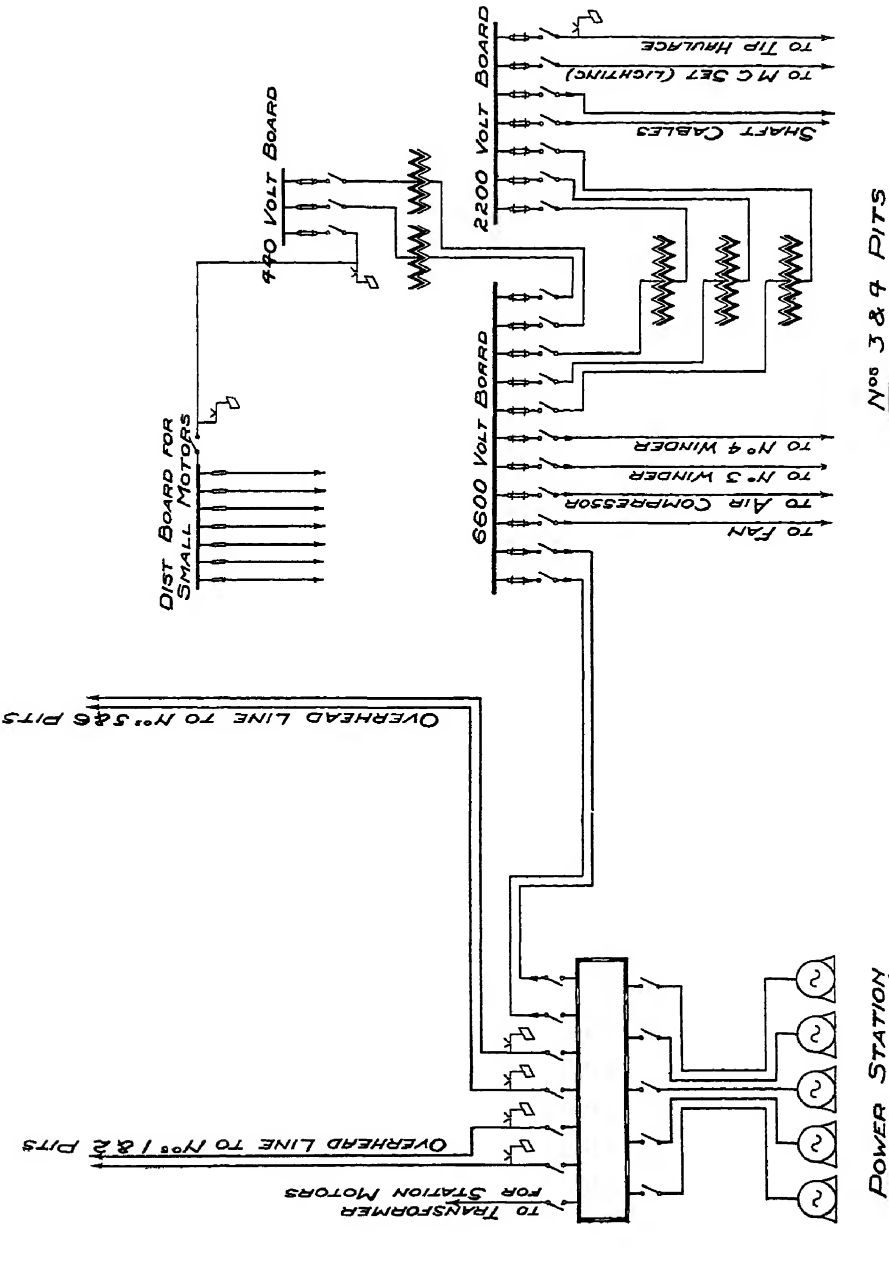

FIG. 18 Distribution diagram for a colliery

work being done piecemeal without comprehensive views being taken and proper plans being prepared of what were likely to be the ultimate requirements of the mine. It is quite easy to make mistakes in this way, particularly in cabling, as it may be put in much too small for the work.

In preparing a scheme plans are necessary. Fig. B8 shows a diagrammatic lay-out of a power station supplying two pits in the vicinity and two other pairs of pits at a distance. The energy is generated at 6,600 volts and stepped down for small motors at the different pits.

Fig. B9 shows a plan of two pits and the haulages in the vicinity of the shaft bottoms, as also a section of the shafts. The cables are shown thereon, as it is quite convenient and better practice to do so.

If a scheme is laid out complete in this way it is easy to carry it out in sections with confidence that the whole will be a harmonious and economical undertaking.

Switch-gear.—The onerous conditions which obtain in mining work call for special switch-gear, and have led to the almost universal adoption of ironclad enclosed apparatus and of oil-immersed switches. Not only must mining switch-gear be designed to withstand very rough usage and for working in unfavourable surroundings, but in many cases the switch-gear will have to be what is incorrectly called "explosion proof." The term "explosion proof" is used for want of a better. What is meant by explosion proof switch-gear is switch-gear designed in such a way that it is impossible for it to cause an explosion of gas in the switch-room, and in the event of gas being exploded in its case, it must be able to withstand the shock of the explosion without breaking or causing any external effect.

An explosion may be caused by the ignition of fire-damp or of carboniferous dust; it is now agreed that the latter plays a most important part in the matter.

It was soon recognised that the adoption of oil-break switches, where the circuit is made and broken in oil, would meet the case as far as the switch proper is concerned. Unfortunately, sparking may occur at other parts beside the switches, say when

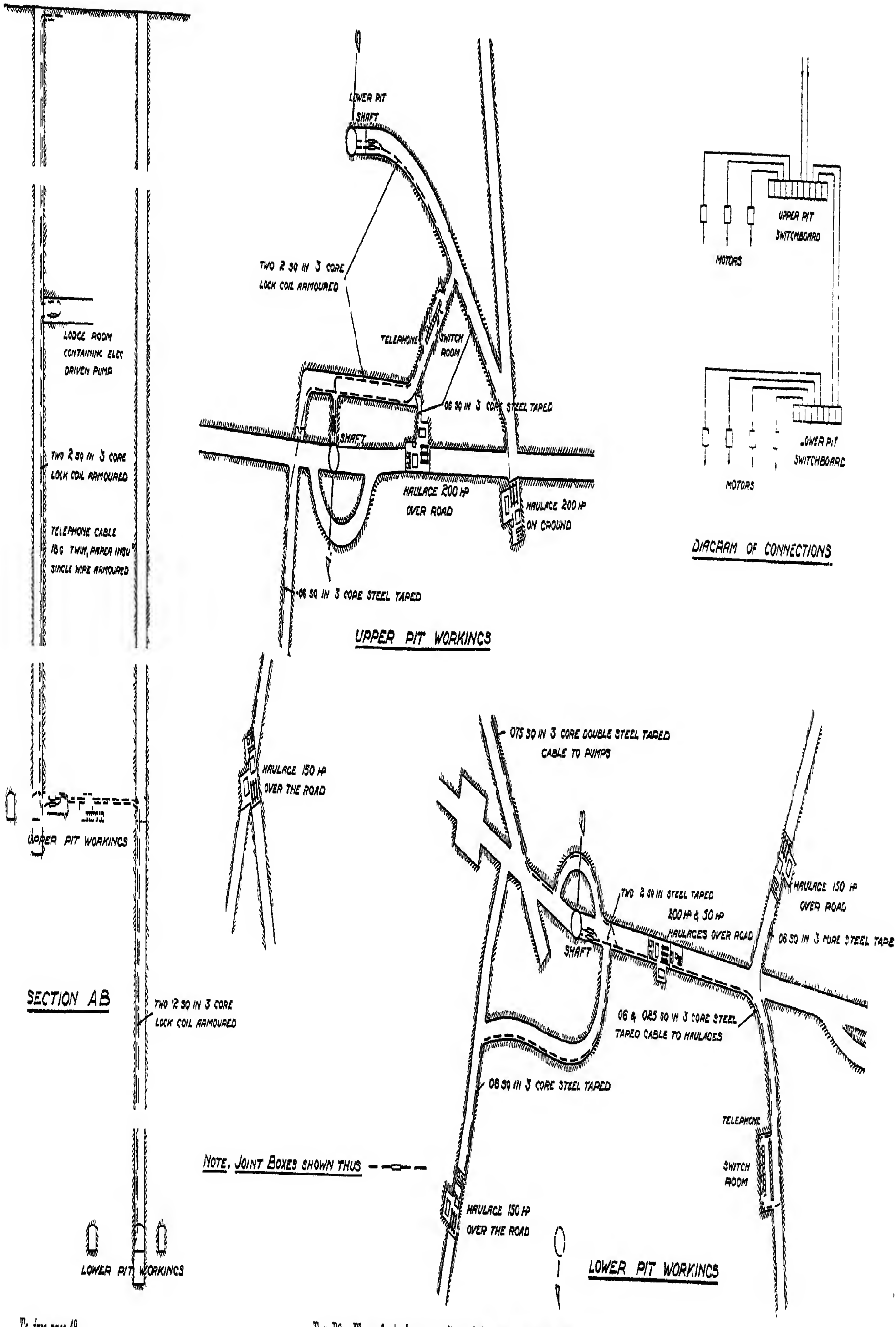

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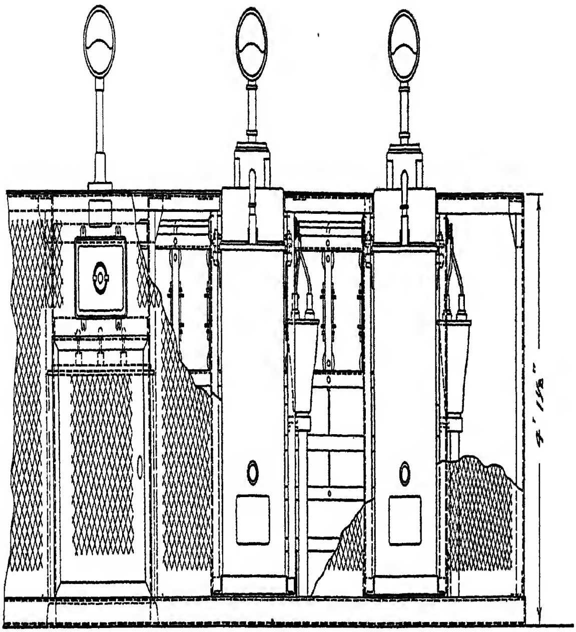
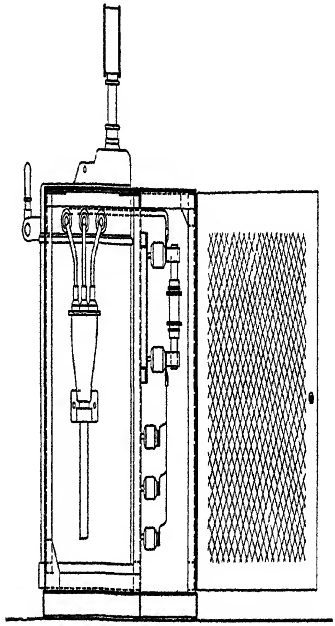
FIG. B9 —Plans of pits showing position of electrical apparatus underground



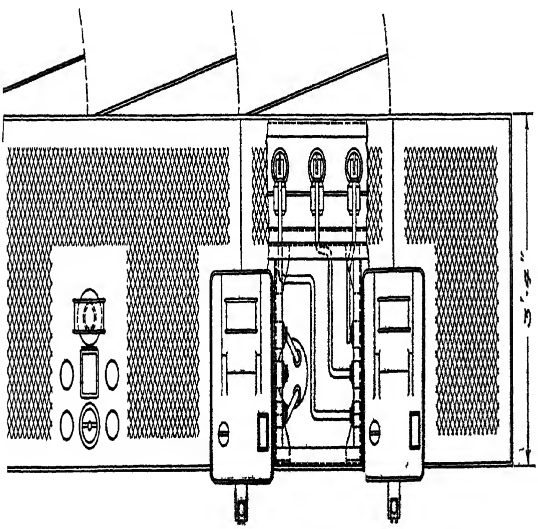
VOLTMETER PANEL   SWITCH PANELS

PART OF FRONT ELEVATION

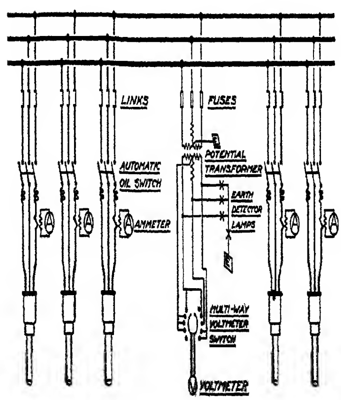


CROSS SECTION

NOTE THE SWITCH PANELS TO INCOMING AND TO OUTGOING CABLES ARE ALIKE, AND ARE ON OPPOSITE SIDES OF THE VOLTMETER PANEL



PART OF PLAN



OUTGOING CABLES   INCOMING CABLES

DIAGRAM OF CONNECTIONS

To face page 48.

a connection works loose through vibration, and so on. To overcome this some makers fill any empty spaces with insulating compound to prevent the accumulation of fire-damp or dust. In the case of boxes which cannot be run in solid with compound because they contain moving parts or mechanism, it is now the usual practice to make these boxes strong enough to withstand an explosion. Some makers construct their switch-boxes to withstand a pressure of 200 lbs. per square inch, this being estimated sufficient to cover any explosive effect. It should be superfluous to say that fuses are unsuitable for fiery mines.

Speaking generally, the essential features of mining switch-gear should be as follows :—

Great reliability and strength , fool-proofness ; simplicity ; non-flammable ; accessible ; possible isolation of any circuit without interfering with the working of the others ; automatic tripping gear.

The jointing of explosion-proof boxes, &c , by the insertion of joints or rubber rings has been found unreliable The only safe joint to adopt appeared to be a broad machine-faced joint, which, when closed by screwing up or otherwise, comes into close contact without the aid of any jointing material When horizontal joints of this kind are used in dirty situations the inevitable result is the straining of the joint by closing it on grit. This has led to the development by the Diamond Coal Cutter Co. of a broad-flanged joint packed with a rubber ring which is heavily braided, impregnated, and cemented into a groove in one flange. The box is also provided with flame-proof ventilators, which offer a lower resistance to the escape of gas explosions than the broad joint, even in the event of the ring being damaged or removed. These joints have been tested thoroughly and found to be flame-proof and fool-proof.

Fig. B10 shows an ironclad type of switchboard which was very largely used at the Ferndale Collieries. It is made up of independent units, so that single units were used for motors and rows of units were assembled and connected by busbars for switch-boards, which is advantageous from the point of view of interchangeability and stock.

Where a group of small motors are to be supplied from one

centre a safe and cheap form of distributing board is necessary. Fig. B11 which shows a Felten Guilleaume design that has proved very useful as meeting such a need.

Various types of mining boards have been designed incorporating the above features to a greater or less extent.

Gate-end Boxes.—The junctions between the haulage roads and the temporary roads along the working faces are called gate-ends. Permanent cables can only be laid in the permanent roads and are finished off with gate-end boxes, from which the

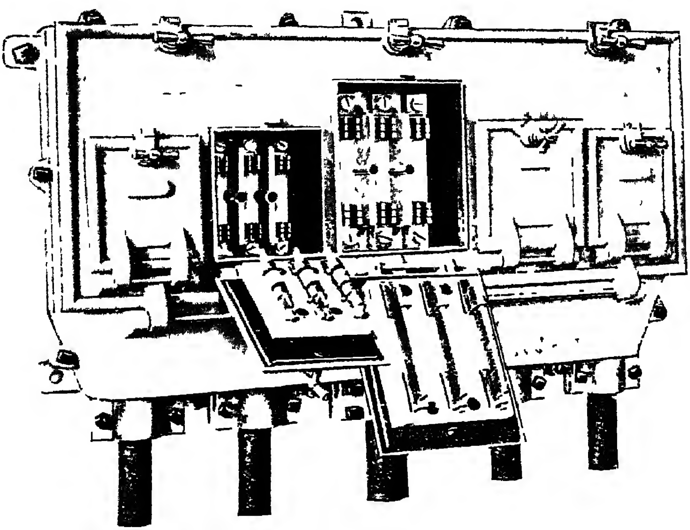


FIG. B11.—Felten and Guilleaume's distribution box.

trailing cables are run to supply drills or small motors for compressors or coal-cutters.

To facilitate the earthing of such motors a special core is often wormed up with, or lashed to, a trailing cable, and special fittings are provided to ensure the connections being promptly and properly made.

The Fisher gate-end box is an elaborate development of this type. The design is neat and complete, but the advisability of using oil switches and delicate mechanism in boxes which are frequently moved, and at best can only be in a temporary position, is doubtful.

The Diamond Co.'s fool-proof gate-end switchbox is of a simpler and more rugged description; it consists of a combined three-pole switch and cartridge fuse-box, with glands for the fixed incoming three-core cable and a specially designed adaptor box for the outgoing four-core flexible cable, the fourth core being for the purpose of earthing the frame of a portable machine. The box is self-locking, explosion-proof

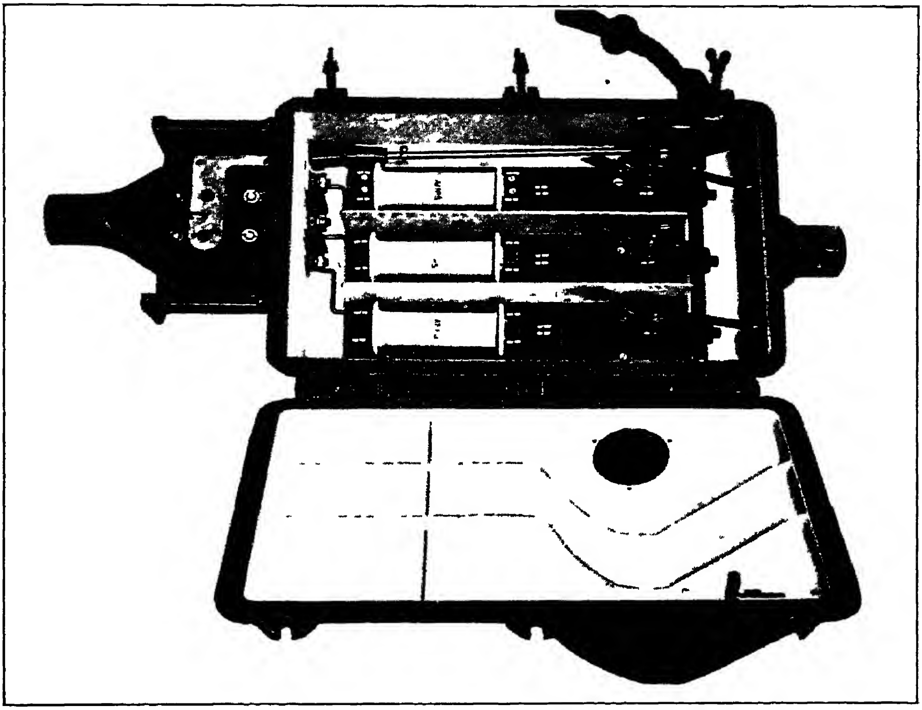


FIG B12—Mavor and Coulson's gate-end box.

and flame-tight. When the switch is on the lid is locked; when the switch is off the lid can be opened, but the switch cannot be closed with the lid open. The adapter can only be put into position when the lid is open, and when the lid is closed the adapter is locked in position.

Messrs. Mavor and Coulson generally use three independent switch, fuse, and plug-boxes made up on a panel in preference to a combination box. They also make a neat box in which

cartridge fuses and a three-pole switch are combined (Fig. B12).

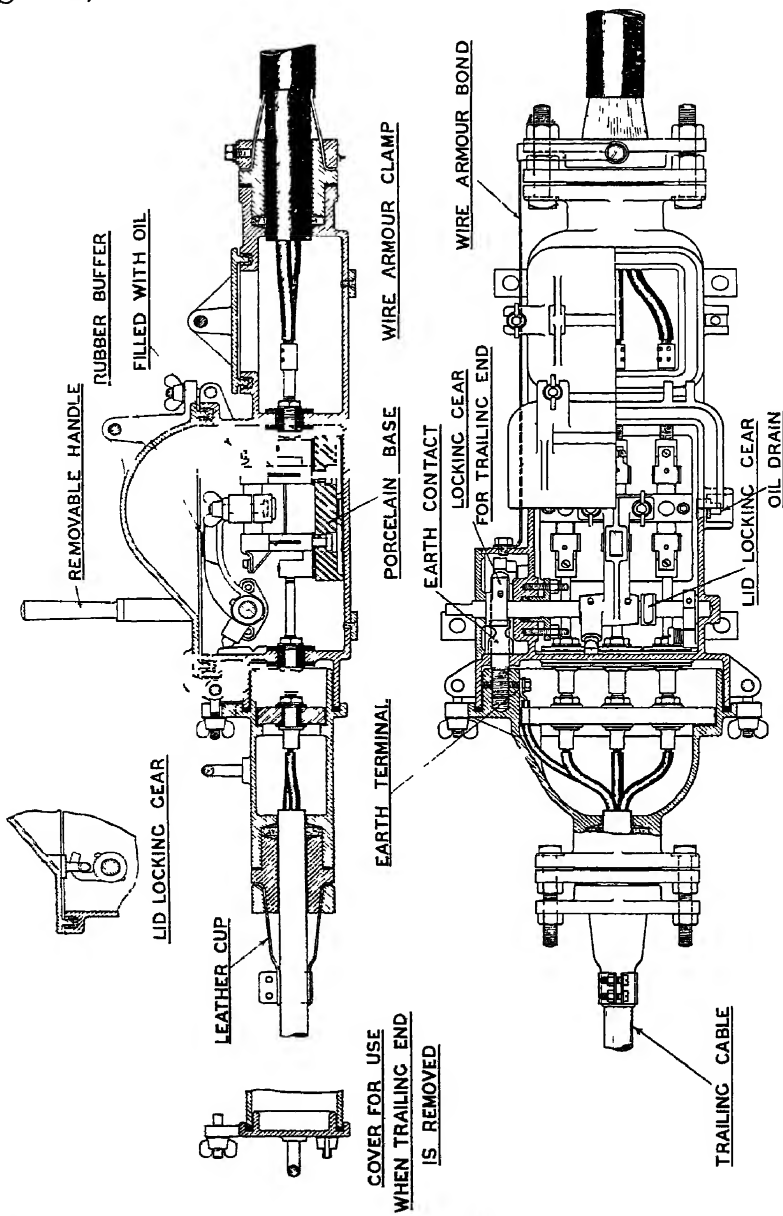


Fig B13 —Callender's gate-end box.

Messrs. Callender's latest type of gate-end box is shown in Fig. B13. It consists of a three-pole switch and three open

fuses arranged in an oil-filled box, the internal dimensions of which are kept down to the minimum. The details are clearly shown in the figure.

Trailing Cables on the surface are always a source of anxiety, and call for special care both in their design and use ; underground the conditions of working are even more adverse owing to the absence of light, presence of moisture, and opportunities for rougher usage.

The cable may be dragged over rough and sharp stones, or even be struck with a tool ; and a cable, to be sufficiently protected to exist under such conditions and yet be flexible and light enough to serve its purpose, can only be the result of a skilful compromise

The conductor is naturally of fine wire stranded , pure Para rubber, with two coats of vulcanised rubber of greater thickness than usual standards, is generally employed The cores are often sheathed in bitumen and made up single or into multicore cables as required. and finished with metallic or leather plaiting, mattress, twine, or hard cord, impregnated, where necessary, with waterproof compound. Sometimes hose-pipe coverings are used, into which the cables are drawn

The ordinary makes of trailing cables, while lasting a fair time under dry conditions, are rapidly upset by the additional troubles caused by moisture, both in regard to disintegration of protective covering and by the additional conductivity given to the fibrous coverings by the moisture and coal dust combined, which allows the electricity to leak from the terminals.

The ideal protection for a trailing cable is that it should be absolutely waterproof ; it should resist the action of corrosive water, it should be exceedingly flexible and not capable of being kinked. Lightness is also a great factor in view of the lengths that have to be pulled about, and a smooth surface prevents abrasion and adds to the convenience of the men at the coal face. Further, a small overall diameter saves bulk when coiled up on the drum, and above all it should stand very rough usage, and after abrasion, say from a fall of coal or other heavy weight being dropped on it, it should return to its original shape.

For dry situations the fibrous protected cables, such as those braided with hard cord, are fairly suitable ; as are also leather-sheathed cables, as these resist abrasion to a considerable extent, and when the protection is cut it does not quickly put the cable out of use as where wire-wound or other armoured protection is used

Special attention should be drawn to the disadvantages of armoured cables for trailing purposes, as if a spiral wire armour protection is used a heavy fall flattens out the wires permanently, so that they are continually biting on the insulation and in a short time cause an earth

Metallic braided cables, when damaged, are unsafe, as the points of the braiding wires either stick outwards and injure men's hands or stick inwards and injure the cable.

Troubles from kinking are also very common, and the worst usually occur with armoured cables, as these retain the kink more than other types, with greater risk of damage to the insulation than in fibre - protected or leather - sheathed cables.

It should be remembered that such trailing cables, when damaged, are positively dangerous to life, to look at it merely from the miners' point of view ; but, looking at it from the colliery managers' or owners', there is the additional loss of output due to the coal cutting or other machine being stopped while the cable is being repaired, or a spare length is sent down and fitted up, together with the cost of repair, or frequently the cost of an entirely new cable.

In this case, therefore, the price should affect the choice of the cable less than any other consideration, and the trailing cable that will last the longest under the severe conditions existing should always be used, almost irrespective of price.

The list of requirements and disadvantages is lengthy ; they are conformed to in part by some classes of cable, and in part by other classes, but one type of trailing cable claims, with good evidence to support it, to embody the complete list. This type is known as Cab Tyre Sheathed Cable and is patented by the St. Helens Cable and Rubber Co., Ltd. In this type the usual indiarubber insulation on the individual cores is

reinforced with a coating of cab-tyre rubber, and the cores are then wormed up with a packing and a heavy coating of cab-tyre rubber, which will resist rough usage, oil and acids better than any other substance which has at present been tried for the purpose.

CHAPTER III

COAL CUTTERS AND UNDERGROUND DETAILS

Coal Cutters.—The mineral deposits which are mined occur in various forms. Metallic minerals occur in veins or lodes, non-metallic in seams or beds and masses. If the vein or seam is a thin one so much greater thickness of rock will have to be removed as is necessary to give access to the vein. In a metal mine where no gases are given off, natural ventilation being generally relied upon, the passages and roadways are not made any larger than are necessary to handle and transport the mineral. In coal mines where gas is given off mechanical ventilation is necessary, and a large amount of air has to be passed through the workings to dilute and carry off the gas and to keep the air pure. In order to pass this air without undue friction and waste of power, the road-ways are made on a more liberal scale.

The mining engineers on the Rand are now facing the ventilation problem and taking their cue from colliery practice In his "James Forrest" Lecture, 1911 (*Proc Inst. Civ. Eng.*, Vol. CLXXXVI.), Dr. Hatch stated that the Crown Mines group has put in hand a gallery 14½ ft. wide and three miles long for a main haulage road, and which is intended to serve also as the intake of the fresh air current.

In working the mineral it is necessary to so arrange matters that property on the surface is not destroyed by the settlement of the ground owing to the removal of its support. The faces or stopes at which the mineral is worked must therefore be as restricted as possible; no more spoil must be brought out of the mine than is necessary, and care must be taken in packing the voids or goaf left by the removal of the mineral, and especially the roof and sides must be adequately supported to afford protection for the men working at the faces.

To meet these requirements in coal mining two principal systems of working are employed, "pillar and stall" and "long wall," with various modifications of them. In pillar and stall, supporting pillars are left between the stalls in which the hewers work, so that the openings at the coal face are in the form of chambers comparatively narrow and necessarily irregular. In long wall working a long face of coal is exposed, the worked coal being carried along the face to the "gate" or end of gallery, or haulage-way at the end of the face, or to convenient intervals along it. When coal is hewed by hand the long wall becomes a waved line, the amount of its departure from the straight depending on local conditions.

As mentioned earlier, a very large number of accidents occur through falls of roof and side; many of these occur on roadways but the majority at the working places, owing to the ground not being made secure Systematic timbering has received a great amount of attention of late years, and anything which will tend to straighten the faces helps in this direction by facilitating inspection and controlling carelessness.

Economic conditions in connection with increased output and improvement in quality have led to the adoption of coal-cutting machines, the output from which is best when a straight uninterrupted run can be obtained, so that their adoption has assisted greatly in the direction of systematic timbering.

The introduction of new methods is invariably opposed by local prejudice, but when the methods are right they ultimately win favour. The "iron-man's" position is becoming more and more secure; he has come to stay just as surely as the motor-bus and the taxi-cab!

Coal cutters can be driven either by compressed air or electricity. Owing to the low air pressure available at the face, the most powerful machines are the electric-driven ones, and when there is no risk of danger from gas or dust they are the most popular.

Table C1, which has been prepared from the Annual Reports of H.M. Inspectors of Mines, shows the growth of coal cutting machines in the United Kingdom.

TABLE C1

Year	Number of Collieries where Machines are Employed	Total Machines	Type		Total Tons Cut by Machines
			Compressed Air	Electric	
1901	No data	345	No data	No data	3,044,321
1902	166	483	334	149	4,161,202
1903	225	643	231	412	5,245,578
1904	249	755	270	485	5,744.044
1905	295	946	500	446	8,102,197
1906	333	1,136	685	451	10,202,506
1907	390	1,493	850	643	12,931,256
1908	414	1,659	922	737	13,590,358
1909	420	1,691	914	777	13,769,687
1910	432	1,959	1,086	873	15,878,801

The average output in tons cut per machine in 1910 was :—
Electricity 10,200 Compressed Air 6,400

The following types of mechanical cutters were employed in the United Kingdom in 1910 :—

TABLE C2.

Type	Motive Power	
	Electricity	Compressed Air
Disc	504	426
Bar	261	72
Chain	107	27
Percussive ..	1	555
Rotary heading ..	—	6
Total..	873	1,086

The different types of machines are suitable for different coal seams. Three only will be described to give a general idea of their characteristics.

Disc and Chain Machines.—These machines have much in common, the disc being an exaggerated circular saw, and the chain a type of band saw. Picks or cutters are secured on the periphery of a wheel, or to a chain running round a driving and a guide wheel, held by an arm or jib bracketed to the side of the machine.

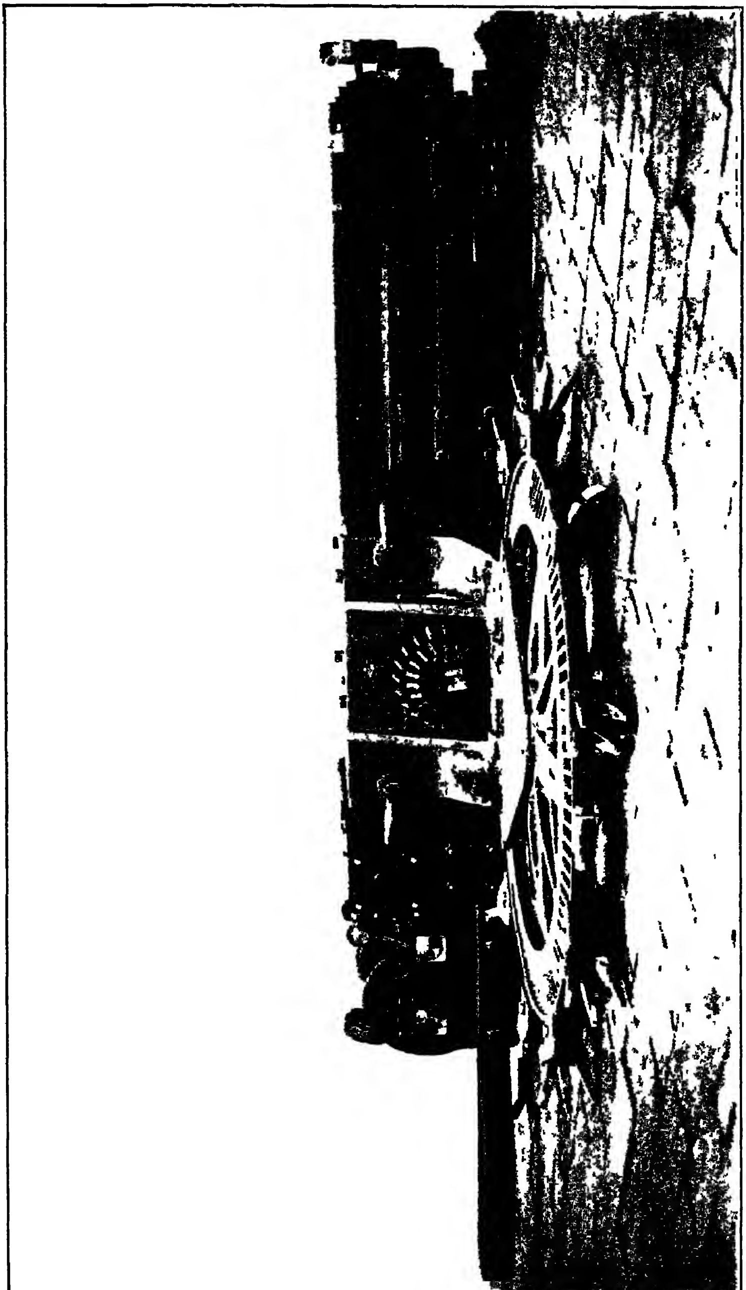


FIG. 61.—"Diamond" disc coal-cutter.

In the *Disc* Machine, the construction must be very rigid to carry the wheel up to 6 ft. diameter, so that a heavy cut can be put on, but the braking action of tender coal as it falls on the sides of the wheel is great, so the machine is only suitable when a clean cut can be ensured. The high power needed for starting the machine has made continuous current or slip-ring motors most suitable. Fig. C1 shows the Diamond Co's Disc Machine, one special feature in which is the cutter box, which is used for attaching the cutters to the wheel. The whole of the ten boxes can be changed in a few minutes, so there is no excuse on this score for using dull cutters, and to this feature the success of the machine is largely attributable.

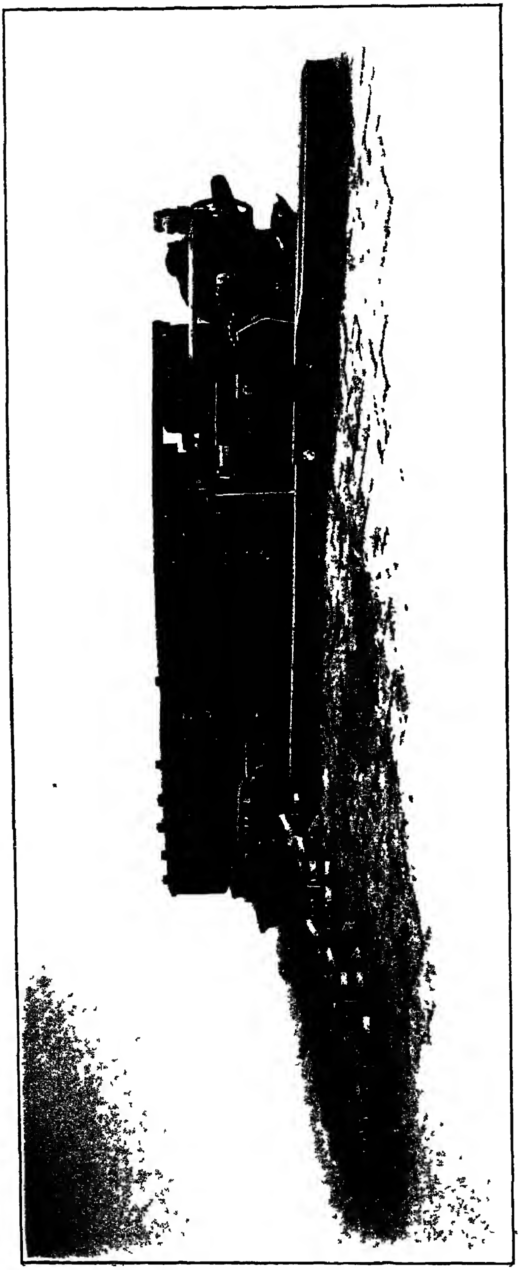


FIG C2.—"Diamond" chain coal-cutter

Chain machines present less surface for friction by their narrow jib, but are not so rigid as a disc machine. They are

used where the coal is tender, and liable to settle down and so act as a brake on a disc machine. Squirrel cage motors may be used for them when slip-rings are objected to, as the starting current is not so heavy as in the disc type. Fig. C2 shows a chain machine made by the Diamond Co., which cuts in both directions without having to turn the machine round.

Bar Machines may be used where the coal is too tender for either of the above types, as they have the advantage of

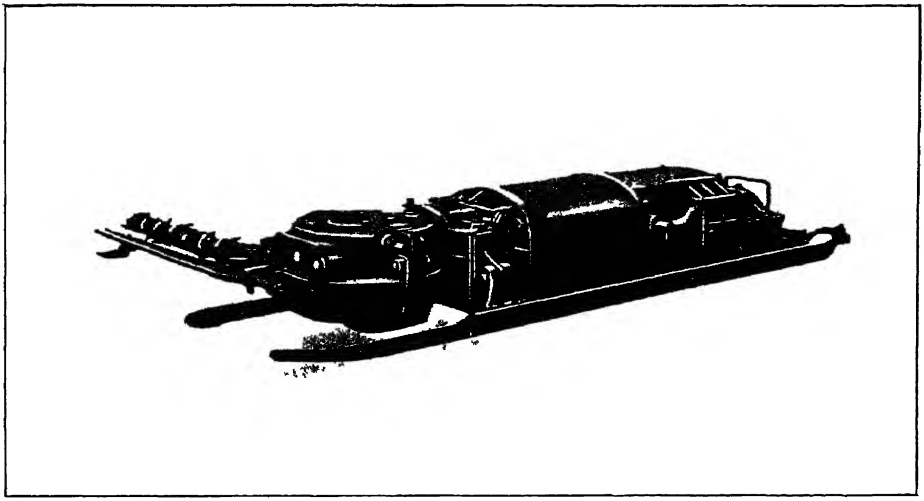


Fig. C3 —Mavor and Coulson's "Pick-Quick" coal-cutter

presenting a relatively small braking surface to a fall of coal. Fig. C3 shows the "Pick-quick" bar machine made by Messrs. Mavor & Coulson. In this type the cutters project radially from a taper steel bar with a coarse pitched worm formed on it. The bar runs at a speed of about 500 r.p m., milling a groove into the coal, the dust being partially cleared out of the cut by the worm ; the remainder serves as a cushion for the coal to settle down upon. The bar is carried by a head which can be turned in an arc of about 180° in a horizontal plane, or with a considerable upward or downward inclination, and locked at any desired angle.

Standard Sizes.—Table C3 sets out the leading dimensions and particulars of some standard bar, disc and chain machines supplied by Messrs. Mavor & Coulson, and the Diamond Coal Cutter Co, respectively. The height is an important feature, and must be considered surprisingly small when it includes a 30 h.p. motor The difficulties in the design have been overcome in a remarkable way by the English makers who in this class of machine lead the world.

The usual voltage employed is 400—500. The motors have to be totally enclosed on account of dirt, even where there is no risk of gas, and very small in diameter on account of the thin seams in which the machines have to operate. One or two motors may be used which drive the cutters through machine-cut hardened gearing running in oil boxes. The machines stand on long slides or skids, and draw themselves forward to follow up the cut by winding up a rope on to a winch driven off the gearing of the machine with an adjustable feed; the fast end of the rope is secured to a prop set on ahead.

Machines can undercut to the depth of 5½ to 6 ft., the rate of travel being anything up to an average of 30 to 35 yards per hour on a sixteen hours run.

A point that requires much more attention than it usually gets is the design and maintenance of the bushings intended to protect the cables from injury where they pass through the motor or switch cases These bushes are too often of very flimsy construction and insecurely fastened in position.

Owing to the simplicity in the cable connections, the high efficiency, and the excellent starting torque of small continuous current motors, that system has hitherto been most commonly employed.

The size of motors adopted varies from one 10 h p. to two 16 h.p. per machine. In some of the large machines one 30 h.p. motor is used, but the two motor type is found to take less energy for the same output.

The amount of energy consumed does not vary much for the same output on a bar or disc machine, but the variations on a disc machine are much greater than on a bar machine, as the latter is not subject to the braking action of the falls of coal before referred to. The maximum current called for is

TABLE C3

COAL CUTTERS—C.C. MOTORS.

Type	"Pick-Quick" Bar			"Diamond" Disc		"Diamond" Chain	
Length	8 ft 8 in	10 ft. 8 in.	11 ft. 6 in	10 ft. 0 in.	10 ft. 0 in.	9 ft. 0 in.	10 ft. 0 in.
Width	3 ft. 4 in.	3 ft 9 in.	3 ft 10 in.	3 ft 6 in.	3 ft. 6 in.	3 ft. 6 in.	3 ft 6 in.
Height	1 ft. $3\frac{1}{2}$ in.	1 ft 8 in.	2 ft $1\frac{1}{2}$ in	1 ft. 5 in	1 ft 6 in	2 ft 1 in	1 ft. 6 in.
Weight in cwt. ..	29	43	56	49	55	45	40
Depth of cut ..	3 ft 6 in	4 ft 6 in.	6 ft. 0 in.	3′ 6″ 5′ 6″	3′ 6″ / 5′ 6″	3′ 6″ / 4′ 6″	3′ 6″ / 5′ 0″
H.p. of motor ..	12	22	26	2 by 12	30	2 by 12	24
Voltage	450/550	450/550	450/550	400/550	400/550	400/550	400/500
R.p.m. of motor	900	900	900	700	800	700	800

COAL CUTTERS—THREE-PHASE MOTORS.

Type	"Pick-Quick" Bar			"Diamond" Disc	"Diamond" Chain
Length	9 ft 3 in.	11 ft. 0 in.	11 ft 9 in.	10 ft 0 in.	10 ft. 0 in.
Width	3 ft 2 in.	3 ft 9 in	3 ft 10 in	3 ft. 6 in	3 ft 6 in.
Height	1 ft 5 in	1 ft 11 in	2 ft $3\frac{1}{2}$ in	1 ft 6 in	1 ft 6 in.
Weight in cwt. ..	28	46	62	55	50
Depth of cut ..	3 ft 6 in	4 ft 6 in	6 ft. 0 in.	3 ft. 6 in. / 5 ft. 6 in.	3 ft. 6 in. / 5 ft. 0 in.
H.p. of motor ..	12/15	18	26	30	24
Voltage	450/550	450/550	450/550	400/550	400/550
R.p.m. of motor	900	900	900	800	800

about in the proportion of four disc machines to six bar machines of equal rating (*Proc. S Wales Inst Eng*, Vol. XXVI., p. 1036).

The easy starting and small risk of jamming a bar cutter makes this type peculiarly suitable for driving by an alternating current Squirrel Cage motor. The worst difficulty in working electrically on alternating current is in connection with the overload safety devices. These must be set at a reasonable margin over the working current, and care is needed to operate the machine in such a way that the starting current does not bring the safety device into action. Clutches are an abomination in such machines and to be avoided, so it is easy to see that if a machine is stopped with its cutter-wheel in the coal a heavy overload on restarting is a certainty. The alternative is for the operators to clear the machine by hand, a task which is little appreciated by them, and only resorted to after ascertaining that the machine will not clear itself.

Compressed Air v. Electricity.—The comparison between the cost of driving compressed air and electric coal cutters is difficult, since as a rule the generator or air compressor supplies power to a lot of machinery other than coal cutters. It may be taken, however, as a rough and ready rule that starting from the boiler a compressed air long-wall machine requires from three to four times more power than one electrically driven. It is frequently very much more than four times, and is probably never less than three times. A few figures are, however, available.

In his evidence before the Royal Commission on Coal Supplies, 1904 (Cd. 1991), Mr. M. Deacon stated that "the efficiency of air transmission rarely exceeded 20 per cent. of the power indicated in the steam cylinder of the compressing engine." The compressed air coal cutter taking 20 b.h.p. will therefore require that 100 i.h.p. be developed in the steam cylinders of the compressor. The corresponding efficiency of electric driving, allowing for a transmission loss as high as 10 per cent. in the cables, would be from 60 to 65 per cent., which means that only 32 i.h.p. would be called for in the steam cylinders of the compressor plant to give 20 b.h.p. at the electric driven coal cutter.

Mr. G. E Stringer in his evidence before the Royal Commission on Coal Supplies, 1904 (Cd. 1991), gave the results of tests which showed that with a compound steam engine driving a dynamo the fuel consumption for electric coal cutters was equivalent to 7 3 lbs per square yard undercut. With a compressed air plant and a simple engine the fuel consumption for compressed air machines was 52 lbs per square yard undercut.

Mr. Sam Mavor has been good enough to give the author a few general figures. At a Scotch colliery from six to eight electrically driven machines are operated every night from a continuous current plant which supplies current for coal cutting only. The fuel consumption per night is one ton of washed dross. A neighbouring colliery operating compressed air coal cutters working under similar circumstances uses four tons of washed dross nightly.

In the case of a compressed air coal cutter operated from an in-bye motor-driven compressor the result ascertained by a six hours test was that during four hours actual cutting the energy put into the electric motor was equivalent to 3 B T U per square yard undercut This test was not very favourable to compressed air working, as the compressor was not fitted with an unloading device and was running at practically full power during the whole six hours The gross consumption of energy amounted to about 4 5 units per square yard undercut. An electrically driven bar machine cutting in the same seam would absorb 0·3 units per square yard undercut.

The figures in Table C4 are results of tests of the performance of coal cutters published in *The Electrician*, 12th May, 1911, and Table C5 is from data by Messrs. Mavor and Coulson.

TABLE C4.

Time.	Depth of Undercut	Yards Cut	Units Used	Units per Lineal Yard.
2 hrs. . ..	4 ft. 6 in.	40	12 0	0 3
3 hrs. . ..	4 ft. 6 in.	60	20 0	0·33
1 hr. 54 min.	4 ft. 6 in	35	11 9	0·34
2 hrs. 15 mins.	5 ft. 6 in.	40	24 0	0 6
2 hrs. 20 mins.	5 ft. 6 in.	45	25 0	0 55
1 hour ..	5 ft. 6 in.	28	15·5	0 55

TABLE C5.

MESSRS. MAVOR AND COULSON'S PICK-QUICK MACHINE.

Period of Working.	Depth of Cut	Energy per Square Yard Cut	Energy per Ton Produced	Total Cost d/d to Haulage	Previous Cost by Hand Holing	Saving by Machine
		Unit	Unit	Per Ton.	Per Ton	Per Ton.
One year	5 ft 3 in	0 53	0·35	2*s* 5*d*	3*s* 11*d*	1*s* 6*d*
One year	3 ft. 10 in	0 26	0 24	1*s* 8½*d*	2*s* 9*d*	1*s* 10½*d*

It will be noted that the energy consumed per square yard undercut by the Pick-quick Bar machine is from about ¼ to ½ a B.T.U. of electricity. In some easy cases the energy used may be as low as 0 2 unit per square yard undercut, but in hard stone it will run up to 0·8 unit per square yard. A moderately strong fireclay requires about 0 4 unit per square yard undercut. These figures show what the machine is doing when it is working on its full cut. As a machine is not always working on its full cut, and may sometimes be running at a comparatively low load, it is safer to allow 1 unit per square yard undercut.

Interesting figures are available from the test taken on coal cutters by Mr. J. P. Winstanley at Westhoughton Colliery, January, 1912 (*Iron and Coal Trades Review*, Mar. 15, 1912), and are given in Tables C6 and C7.

(1) *Gillott Compressed-air Coal-cutter* (*Disc Type*) :—Alley-MacLellan water-cooled single-stage air compressor on surface, for dealing with 700 cubic ft. of free air per minute at a pressure of 60 lbs. per square inch.

TABLE C6.

No. of Test.	Hours Cutting.	Yards Cut.	Under-cut Feet	Total Square Yards Cut	Total Units.	Units per Square Yard	Square Yards per Hour
1 ..	15	155	2½	129	610	4·72	8·60
2 ..	11½	150	2½	125	510	4·08	10·90
3 ..	14	162	2½	135	590	4·37	9·65
4 ..	13½	158	2½	132	590	4·47	9·80
Totals and averages	54	625	2½	521	2,300	4·41	9 74

Driven by 140 h.p. Westinghouse three-phase motor.

Compressor when driving this coal cutter was working at about 75—80 per cent. of full load

Coal cutter working 690 yards away from compressor.

Width of cutter, $4\frac{1}{2}$ inches.

(2) *Hopkinson Electrical Coal Cutter (Chain Type)* :— Driven direct by 25 h.p. three-phase motor ; coal cutter working 1,430 yards from point where current is metered.

TABLE C7.

No of Test	Hours Cutting	Yards Cut	Under-cut Feet	Total Square Yards Cut	Total Units	Units per Square Yard	Square Yards per Hour
1 .	$6\frac{1}{2}$	64	$3\frac{1}{2}$	74.6	104	1.40	11.5
2 ..	6	45	$3\frac{1}{2}$	52.5	43	0.82	8.7
3 ..	$6\frac{1}{4}$	72	$3\frac{1}{2}$	84.0	105	1.25	13.4
4 ..	$5\frac{3}{4}$	56	$3\frac{1}{2}$	65.3	85	1.30	11.4
Totals and averages	$24\frac{1}{2}$	237	$3\frac{1}{2}$	276.4	337	1.19	11.3

Mr Winstanley states that the coal in the case of the electrically-driven motor was of the two very much harder to cut. As regards up-keep the advantage lay with the electrical cutter.

Percussive.—It will be appreciated that the output from a coal-cutting machine of any of the above types depends upon the length of face along which the machine can be moved intact and without dismantling, as dismantling and reversing in order to work back along the face takes time. Where the face is short, as in stalls, such machines are unsuitable, as the time lost in dismantling would approximate the working time, and the machine would be too heavy and clumsy to put on one side while the coal was being cleared. In stall working, therefore, a machine which is rather of the Drill than Cutter family is used, although when adapted for use in coal mines they are called cutters.

The most popular type is the "Percussive" machine, in which the tool is attached to a piston, which is reciprocated by some means. Compressed air is the simplest method of working

the piston; although several machines of the class have been developed for electrical driving, the compressed air machine is still used to a far greater extent than those which are directly driven by electricity.

The earliest machines of this type, known as "Punchers," were mounted on small wheels, and weighed complete some 500 to 700 lbs., so that they could be removed without much difficulty from one working place to another. In operation the machines are mounted on a wooden platform packed up at the back end so that the recoil is neutralised by gravity, and the machine runs forward to follow the cut into the coal. This class of machine is greatly used in America, but has never been popular in this country, due to the vibration caused to the operator, who sits behind it guiding and pressing it forward down the sloping platform.

"Siskol."—To overcome this objection the "Champion" Coal Cutter, which has latterly been called the "Siskol," was brought out by the International Channelling Machines Ltd. This machine is worked from a rigid support or column with a screw jack in the head of it, by which it may be secured in position, and may be used either as a coal cutter or as a drill, the difference being in the attachment between the cylinder and the pillar. When the machine is set to work the cutter strikes the coal at the rate of 200—350 blows per minute. If it is desired to drill a hole the tool is directed to one spot, but if it is desired to cut a groove in the coal the tool can be moved round by the quadrant-shaped racking motion, the attendant operating the feed forward with one hand, while he controls the direction of the tool with the other.

When the cylinder has been advanced to the full extent of the feed screw, *i.e*, 18 in. to 24 in., the machine is stopped, the cylinder screwed back, and the cutting bit replaced by a longer one. The machine has a piston 3½ in. in diameter, with a stroke varying from 4 in. to 7½ in. The valve is air driven, the special feature in the design being the air cushion in front of the piston, which prevents the piston from striking the front cylinder cover should the cutting chisel miss the coal and strike into a void. The drill part of the machine weighs about

240 lbs., the segment 112 lbs., and the column about 200 lbs., depending on its length, so that it is evident that the machine is much more portable than the other types. They will with one setting make a cut up to 20 ft. wide ; the depth is generally limited to 6 ft.

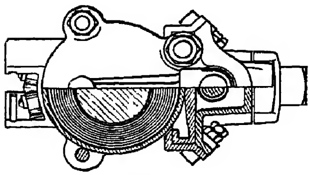
The "Electric-air Radialaxe" of the Ingersoll-Rand Co. is mounted and used in the same way.

Electric Drills.—There are several types of electric drills now in use, the percussive or solenoid, the rotary or motor driven, and the electric-air drill.

In the Percussive or Solenoid type, an iron core is attracted and repelled alternately by the intermittent magnetisation of coils which surround it. There are several different types ; in one type there are three coils, to two of which an alternating current, which is reversed at every half period, is supplied, while the middle coil is energised with continuous current.

One of the latest types is the *Marvin-Sandycroft* drill. This type has only two coils, which are energised alternately with a pulsating current supplied from a special generator. The generator is a 200 volt continuous current machine with an extended shaft, upon which is mounted a Dutton's patent wave-forming device. This arrangement supplies a low frequency, flat topped current curve, by a special arrangement of slip-rings and commutators. The principal feature of the apparatus is that, although a four-pole machine is employed, only one cycle is produced per revolution. Tappings are taken from four points on an ordinary continuous current commutator, as in a single phase rotary converter, and connections are taken from these to two segments of a four-part commutator, with two brushes. The other two segments of this four-part commutator are connected to the two slip-rings, which are connected to the main terminals. Thus the action of the four-part commutator is to take current during successive quarter revolutions from the continuous and alternating current sides in turn, so that the result is a wave lasting over half a revolution. The flat top results from the quarter revolution, during which continuous current is being taken in the appropriate direction. The

divided ring between the ordinary commutator and the four-part ring simply serves to make connection during alternate half-revolutions to the two sections of the coil on the drill. These two coils have a common return, so that only three leads need to be taken to the drill. The standard machines run at 385 r p m.



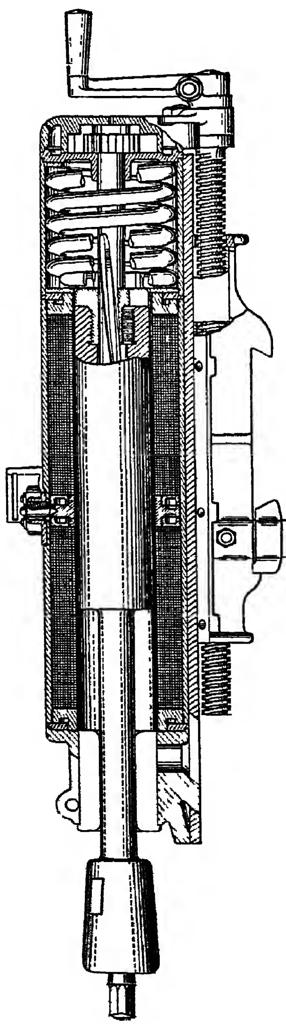


Fig C4.—Marvin-Sandycroft coal-cutter.

The magnetic pull of the coils draws the plunger, to the head of which the drill is attached, backwards and forwards as the current alternately passes through one or other coil; see Fig. C4. At the back end of the cylinder there is a very heavy helical spring, which cushions the backward stroke of the plunger and supplies some of the energy thus momentarily stored to the forward stroke. The coils forming the body of the machine are wound upon a steel tube provided with steel heads, and are encased in a steel jacket which is caulked in place, making the coils entirely impervious to dirt or moisture.

The construction of the coils is designed to meet the rough conditions under which such a machine has to operate. Bare copper wire of square section is used, and is insulated as it is wound with pure mica, no other insulating material being used in the construction of the drill. This renders the coil absolutely fire-proof and eliminates possibility of injury due to vibration.

A 6-in. drill of this type will drill a hole 8 ft. deep and $1\frac{3}{4}$ in.

diameter at the bottom. The stroke is 7 in. and the length of feed 24 in. The weight of the drill is 320 lbs. The current required is 30—35 amperes, and the power required on the pulley of the standard 200-volt generator at 385 r p m. is 7 h p.

The standard generator may be run as a rotary converter off a 200-volt circuit when its output is doubled ; in this case the current-collecting devices are made heavier than when the machine is to be belt driven.

In the Rotary type of drill a rotating cam compresses a spring, which throws the piston forward on the return stroke as soon as the cam has slipped off the disc The cam shaft is motor driven at a speed of from 250—400 r.p m. A drill of this type is only suitable for working downwards, as when working upwards the weight of the drill acts against the spring and reduces the force of the blow.

In the Asbestos Mines of Quebec a drill of this type is used with excellent results, the blows being given through a crank shaft driven by a motor, the drill at the same time being rotated by gearing About 2 h p. is required to work the drill but 5 h.p is required for compressing the air used to blow the dust out of the holes, which are drilled up to 16 ft. in depth. Water cannot be used for the purpose, as it would clog the asbestos dust and choke the drill.

Another drill of the same type used in the Asbestos Mines is of the percussive and revolving, but not reciprocating type. It will carry a 2½-in. tool and when delivering about 300 blows per minute the drill will advance about 3 in. Compressed air is used to keep the hole clear. The drill steels in this type of drill are hollow, and are used to convey the air to the cutting edge.

The *Temple-Ingersoll* "Electric-Air" drill is electrically operated, but is not strictly an electric drill. In this machine the drill is driven by pulsations of compressed air generated by a motor-driven duplex air pulsator. The air is not exhausted to atmosphere, but is used over and over again, as two short lengths of hose connecting the pulsator and the drill, each running from one pulsator cylinder to one end of the drill cylinder and serving for the air admission and return. The pulsator is a vertical duplex single acting air compressor with

cranks at 180°, but with no intake or discharge valves or water jackets. It is geared to a motor, which may be either continuous or alternating, and is mounted on a small truck for convenient transport. The drill is of the simplest possible type A cylinder contains a moving piston and a device for rotating the drill, but there are no valves or small complications. Fig C5 shows an elevation of the electric-air drill partly in section. In the ordinary air drill a cylinder full of air at full pressure is used at each stroke and discharged into atmosphere at practically full pressure, little or no advantage being taken of the expansive properties of the air. In the "electric-air" drill the air is used in a closed system, under a low pressure, and is merely the transmitting agent between the piston of the pulsator and the piston of the drill itself. Air leakage is provided for by a compensating valve, which automatically maintains the requisite pressure in the air circuit. A machine of this type with a 3 h p. motor will drill holes 1½ in to 1¾ in. diameter up to 6 ft. in depth. Larger machines fitted with a 5 h p. motor will drill holes of the same diameter up to 16 ft. in depth.

Electric drills are also made of the Stand type, in which the rotary motion is given by a motor carried on a machine and connected through gearing to the drill, or sometimes a separate portable motor is used and connected to the drill by a flexible shaft. The power taken is from ¾ to 1 h.p. With this type of drill a hollow spindle is often used, through which water is run to the cutting edge, which serves the purpose of keeping the drill cool and the hole clear. A drilling speed of from ½ in. to 5 in. a minute is obtained, depending on the class of rock. This type of drill is somewhat delicate, as when the motor is mounted on the drill the temptation is to make it too light to stand the rough work. When the motor is on the ground and connected by a flexible shaft another detail is incorporated which is by no means free from trouble, as under the best of conditions a flexible shaft is somewhat delicate, and in a mine it may get roughly handled.

A very exhaustive set of Drilling Trials was made on the Rand, as in 1909 the Transvaal Government and Chamber of Mines inaugurated an official contest, offering £4,000 and

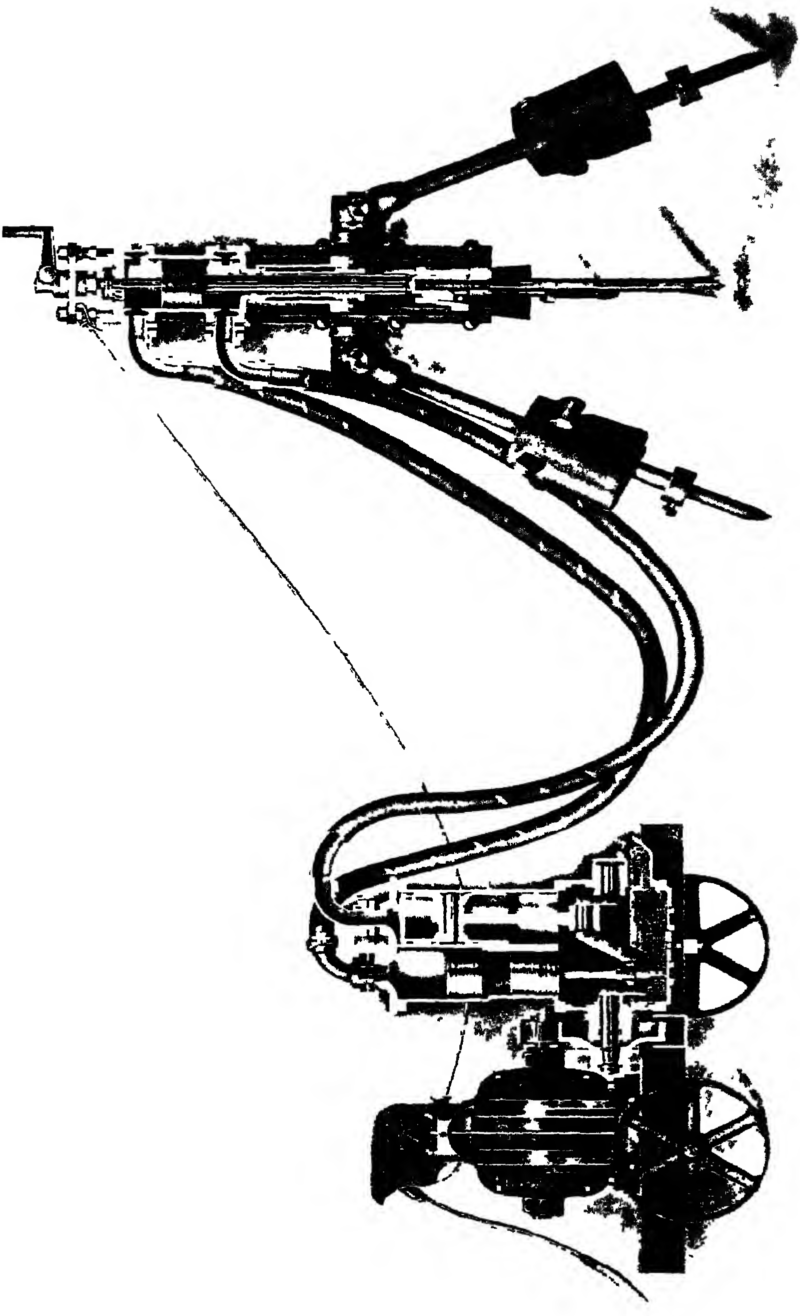


Fig. 65.—Temple-Ingersoll electric air drill

£1,000 respectively to the two most successful competitors. Twenty-three machines were entered, nineteen of which were tested. In May, 1910, the result of the competition was officially announced. The Siskol drill was declared to have dead-heated for the first place with the Holman, and they were each awarded a prize of £2,500. Both these drills are worked by compressed air, but they may both be worked on the electric-air system by means of a portable motor-driven compressor.

Conveyors.—Coal cutters working on the long-wall system offer a tempting field for the introduction of conveyors, but the difficulty in getting a conveyor which will work under the rough and tumble conditions obtaining prevents the employment of anything approaching the elaborate types of conveyor that are used above ground.

It must also be remembered that coal cutters are mostly introduced in the case of thin seams, and in a seam of 18 in. thickness, there is very little room to put elaborate machinery; 24 in., however, is considered fairly liberal. Machine cutting has been introduced into thin seams to enable them to be worked economically, and machine handling for transporting the coal to the gate-end becomes an economical necessity. If extra head room had to be provided for handling the coal after it is cut the value of the machine cutting would be greatly discounted, or in fact the scheme might be uncommercial.

Several conveyors are now on the market on to which the coal can be filled along the face of the wall, and which will deliver it into the wagons at the haulage road at the gate-end. Some of the conveyors are on the band and others on the tray system, and are worked intermittently along the face at a speed of from 100 to 150 ft. per minute; in cases where electricity can be employed a motor forms the handiest means of working the machine, as it can be snugly attached to the end carriage of the conveyor, which it drives through gearing.

The motors employed are from 6 to 10 h.p. The work is very rough, although not quite so rough as the coal-cutting motor has to contend with; the conditions call for totally

enclosing it and everything being made of the strongest, and yet the simplest, description.

The *Blackett* is one of the earliest and best known conveyors, and consists of standardised 6 ft. sections of steel sheet troughs carried on an angle iron framework ; each length can be erected or dismantled without bolt or nut, and each trough can be similarly lifted out for access to the chain beneath. The chain is of special design made by Messrs. Ley, and rides on the small coal, which is dragged along the bottom of the trough while it carries the larger coal. The lower half of the chain returns within the framework underneath the troughs, and a ratchet screw is provided at the tail end for adjusting it. The height of the conveyor itself over the troughs is about 10 in. , the discharging and tail ends are a little higher, but will easily go into a 2 ft. headway. The overall width is 18 in. A conveyor of these dimensions when driven by an 8—10 b.h p motor running at about 600 r p.m., which is generally carried on the framework of the discharging end, will deliver 25—30 tons of coal per hour. One of the earliest "Blackett" machines made by the Diamond Coal Cutter Co in 1904 has been in daily operation since that date, and has delivered some 200,000 tons of coal from a seam barely 2 ft. in thickness.

The *Gibb* conveyor is a combination of a carriage and scraper chain. The conveyor is about 20 in. high and 24 in wide It consists of two end sections and several intermediate sections each 6 ft. long. The end discharge is effected by scrapers attached to a pair of endless chains which are returned under the bottom of the carriage. The discharging end contains a gear, through which the scraper chains are operated by a rope from an independently situated haulage gear. While the carriage is travelling the scraper chains do not rotate, but on arriving at the discharging position a simple trip arrangement releases a wheel, which is then free to rotate and drive the scraper chains. The carriage may be drawn along the face towards the gate-end at a speed of about 150 ft. per minute. When it reaches the stops at the roadway with its end overhanging an empty wagon it automatically operates a trigger and commences to discharge. When the load has been discharged the direction of travel of the rope is reversed by operating the

controller, the trigger re-engages and locks the discharging gear, and the carriage is returned to the fillers. An advantage of this type of conveyor is that the conveyor carriage can be kept out of the way of the coal-cutter men. The whole arrangement is very portable, and its weight and cost are much less than those of a full length conveyor. The capacity of the conveyor depends upon the thickness of the coal seam. The smallest that can be practicably made will operate in a total headroom of 18 in.; such a conveyor with six intermediate sections has a capacity of one ton.

The *Ritchie* conveyor, made by the Diamond Coal Cutter Co., is of the intermittent discharge type, and will deal with any quantity up to 80 or 90 tons per shift during normal working. It is generally used where the quantities to be handled do not justify the installation of a continuous running conveyor of the Blackett type. The conveyor is composed of standardised 6 ft. sections of light steel troughing. These troughs are only 4 in. high on the face side and 8 in. high on the goaf; the overall width is 22 in. A specially strong belt, which is made about one-third the length of the coal face, is hauled to and fro in the troughing by means of main and tail ropes, which may be driven by an electric motor or compressed air engine. The motor is built into the discharging end of the conveyor, which stands on rails at the main gateway and is entirely self-contained. It is quickly and rigidly secured into position by means of two short screw jacks which are set up against the roof. All the gearing and the motor are completely enclosed. The tail rope for working the belt is carried round a return pulley, which may be merely anchored to a prop in line with the troughs. The return speed of the belt is about three times the loaded speed. This conveyor can be used in the thinnest possible working seams, and on account of the lightness of the troughs and the facility with which it can be taken apart and re-assembled it can be very easily and rapidly moved forward and re-erected. The power required to drive it the usual length of about 100 yards is 8 to 10 h.p.

Shaker conveyors are economical as regards the power consumed, but the elaborate construction used over ground is hardly applicable to the conditions of underground service,

although, in many instances, they have been successfully adopted Shaker conveyors have been used on the Rand slung from the roof by short chains which are adjustable by eye-bolts. The arrangement is very cheap and convenient; if it were worth while an electric drive could easily be arranged, but on the Rand they have generally been swung by Kaffirs. Such conveyors have been made 18 in. wide and up to 200 ft. long. The power required for swinging them, as given by Mr. E. G. Way (Proc. Inst. Mech. Eng., 1907, p. 989), who introduced them, varies from about twenty-two men on a conveyor 224 ft. long to three men on one 32 ft. long.

Belt conveyors are excellent and economical where they can be properly fixed, but do not lend themselves to underground conditions on account of the difficulty and expense in levelling them with sufficient accuracy to prevent undue wear and tear of the belt.

Shot Firing.—The firing of explosives is effected by two different systems—the high tension and the low tension.

Small portable generators of the magneto type are generally employed. Portable batteries have been largely employed, but generators are now more popular.

Low-tension fuses consist of small platinum wires embedded in fulminate of mercury, or some similar priming substance, which is fired by the incandescence of the platinum, and in turn ignites the explosive charge; they require about 0·3 ampere at a few volts pressure.

In high-tension fuses the ends of the platinum wire only project into the detonator, and a spark is driven across the chemical compound between them at a pressure of about 80 to 100 volts.

By arranging low-tension fuses in series forty to fifty can be fired simultaneously. There is a danger in arranging fuses in series, as if one goes off too soon it may break the circuit and prevent the remainder being fired; they must be of the same type and size and in good order.

Shot firing is always in the hands of special officials, who are responsible for not connecting up the wires to the magneto until everything is ready, and taking certain other precautions

against risk of danger. Current from lighting or power circuits is not allowed to be used for the purpose on account of the danger of premature ignition. The risk of mis-fire is practically eliminated with electric shot firing if care is taken to see that the firing battery or magneto is well up to the work it may be called upon to do.

Underground Lighting does not usually extend far beyond the shaft bottom or motor rooms.

Low pressures should be employed, preferably not exceeding 100 volts. Here alternating current is convenient, as small transformers give every facility for securing safety with economy. The lamps must be protected, generally with fittings of the "bulk-head type," and, as mentioned previously, insulated wires run on insulators are much better than wires drawn into piping on account of the risk of damage by bent pipes and the inevitable rusting due to condensation.

The danger from faulty hand lamps has already been mentioned, and must be guarded against by the selection of safe types. The faults in certain types have been so frequently advertised by the Home Office Electric Inspector of Factories that there is no excuse for ignorance on this score.

Accidents have arisen from the accidental contact between lighting circuits and power circuits of high potential; this point must be carefully watched, and safe routes with efficient protection selected for each circuit.

Safety Lamps.—Where lamps are lit by hand they may be burning a long time before they are usefully employed, and the consequent waste of oil is a serious item. Economy is effected in many pits where oil safety lamps are re-lit by an electrical apparatus, which consists of an induction coil in a specially constructed box with sunk terminals to prevent open sparking. The safety lámps are fitted with an insulated wire brought through the oil vessel into the interior of the lamp and terminating at the wick. When the safety lamp is pressed down into the box the terminal plates make contact with the lamp body and the insulated wire respectively, and a spark is drawn from the wire to the wick holder which lights the lamp. Such

apparatus is placed at authorised re-lighting stations under ground.

Electric safety lamps are not employed to any great extent in this country. Out of 705,482 safety lamps in use in the United Kingdom in the year 1910 only 2,055 were electric, being a reduction of 100 electric as compared with the preceding year.

The Chief Inspector of Mines states in his 1910 Annual Report, part 2, p. 65 :—

"There seems every probability that had electric hand lamps been in use at the Whitehaven and Hulton Collieries the terrible disasters which took place there during the year would not have occurred; . . . by electric hand lamp is, of course, meant an electric lamp of an approved type; . . . as in the case of both these disasters there is little or no doubt that the igniting cause of the explosion was a gauze safety lamp."

The urgency of the need for a portable Miner's Electric Lamp was so strongly felt by a colliery proprietor in 1911 that he has offered, through the Secretary of State for the Home Department, a prize of £1,000 with a view to encouraging inventors and manufacturers to take up the question. The first prize of £600 was won by the C.E.A.G. Lamp, which was sent in by Mr. F. Farrer of Dartmund The remaining £400 was equally divided between eight other competitors.

The constant straining of the eyes of miners working with oil safety lamps which only give about 0 66 c.p., due to the imperfect lighting, is well established ; better lighting would make for increased output and increased safety with less strain.

An oil safety lamp can only be slightly tilted, so that it is impossible to project the light from it directly on to the roof. An electric lamp, which can be used in any position, has not this disadvantage.

Various attempts have been made with both primary and secondary batteries to develop a reliable electric safety lamp. The low efficiency of carbon lamps was a great drawback ; now that metallic filament two and four volt lamps are available the prospect is much more encouraging.

The *Sussmann lamp*.—Of the 2,055 lamps reported as in use in the year 1910 about 1,800 were of the Sussmann type, and

were in use at the Murton Colliery, Durham. This lamp consists of a secondary battery of the two-cell type with a gelatinous electrolyte; hence it is sometimes spoken of as a dry type in distinction to other types of secondary batteries, the cases of which have to be tightened by screw plugs or similar devices to prevent the acid spilling. The Sussmann lamp weighs 4½ lbs., and will give 1½ c.p. for twelve hours.

The *Wolf lamp* contains one secondary cell in a celluloid case with a capacity of 1½ c p. for ten to twelve hours on the two-volt metallic filament lamp with which it is fitted. The complete miner's safety lamp weighs 4½ lbs.

The *Float safety lamp* is made up with two carbon-zinc cells, and weighs complete 5½ lbs. It gives 8 c.p. for eight to nine hours, falling to 4 c p. by the end of the tenth hour.

The *Pape safety lamp* is designed for use with the "Fors" accumulator. This accumulator has electrodes of the circular type, the positive being placed inside a porous pot, while the negative surrounds it. The lamp cases are of solid drawn aluminium tube with a foot and collar cast on, or are made of light aluminium castings. The trunnion-pins, which carry a yoke, are riveted to the top of the casing by means of lugs, and a set screw through the centre of the yoke serves to hold the lantern firmly in position on to the case containing the battery. One set-screw only is required to make all the joints perfectly airtight. The smaller sizes are fitted with stout cylindrical glass chimneys, sealed at the top and bottom with vulcanised rubber. The complete lamp weighs 3 lbs., and is 10 in. in height by 3¾ in. diameter, and gives 1½ c.p. for twelve hours.

The *Lithanode Unspillable* hand lamp is a novel and interesting type. At present it is enclosed in a square cornered, hard wood case, if it is generally introduced for mining work this will doubtless be altered. The lamp switch is unusual, and it is operated by turning the bezel of the protecting glass through a small arc of a circle. The accumulator is of the Lithanode patent unspillable type, and claims to be the only one on the market that attains its unspillable quality without the use of any packing material between the plates. The principle of the unspillable cell is identical with that of the

unspillable inkpot, a separate chamber being fixed at the side of the accumulator to receive any few drops that may be brought over when the accumulator is gassing A hand lamp complete measures 5 in. by $2\frac{5}{8}$ in. by 7 in. high and weighs 4 lbs. 2 oz. It gives a light of 5 c p. for eight hours

With the exception of the Murton Colliery above mentioned no other pit in the United Kingdom is completely lit with electric lamps, but they are largely used for inspection purposes, and are highly appreciated for rescue work

Signalling.—Electric signalling by means of a bell is in general use in mines, as it is more reliable and rapid than the old mechanical arrangements. It, however, is perhaps more likely to get out of repair and greater skill is required in maintaining and repairing an electric system than a purely mechanical one.

An electric system is commonly used along haulage roads, the wires are usually bare and supported on insulators along the road. Special care must be taken to keep the signal wires clear of any possible connection with the lighting or power circuits. Push-buttons or Morse keys are used as contact makers at the fixed stations; they must be so constructed and fixed that they cannot accidentally close the circuit. The bare wires afford facilities for giving signals from intermediate points, as a contact is readily made across them with a piece of metal. All bells and contact makers must be strongly made; the best types are iron cased. and so constructed that they are gas, water, and dirt proof.

In the 1904 Special Rules 15 volts was the maximum pressure allowed. Under the 1911 Special Rules this has been increased to 25 volts. For longer distances than can be covered conveniently with a 25-volt circuit relays are employed. In the ordinary relay system double wires are used, and the relays are arranged to operate local batteries, which may be either of the primary or secondary type.

A new and ingenious relay system has lately been introduced, where as many relays as there are stations are connected in series with the line wire and the relays in the indicators are tuned to them, hence the section or station in which a contact

is made shows on the indicator. The arrangement makes for safety, as if a "stop" signal is given the motor-man not only knows where it originated, but knows that it will be dangerous to start again from a signal given on any other section; but it is open to question whether this advantage is not obtained at a sacrifice of simplicity and an increased risk of interruption.

Luminous shaft signals are in common use on the Continent in connection with electric winders, but have not found favour here, chiefly owing to the difficulty in working a mixed system of signals. For winding-shafts a heavy rapper, or gong, is used with a well-understood code or system of signals, and it is easy to see the objection to the introduction of a new and elaborate system in one shaft only of a group. There is no mechanical or electrical difficulty in arranging a large number of windows, which can be illuminated by moving a commutator switch and show the legend inscribed thereon, but the mechanical simplicity does not compare favourably with a 7-lb tilt-hammer arranged to strike a piece of loose boiler plate when pulled by a $\frac{3}{8}$ in. galvanised iron wire cord, trusting to the hitchers and banksmen to count the blows!

Telephones.—"Telephonic, or other equivalent means of communication, shall be provided between the surface and the pit bottom or main distributing centre in the pit" forms one of the 1904 Rules for the Use of Electricity. The use of telephones is now much more general and highly appreciated; special types of mining instruments have been brought out to meet the special conditions.

The Western Electric Co. have a model heavily housed in wood impregnated with oil against damp, and covered in sheet lead for mechanical protection. The metal parts are also all lead plated and the coils specially water-proofed. The receiver and transmitter are both inside the box for protection; a flexible tube which also acts as an insulator connects the receiver to the ear-piece. Two-wire insulated lines and local batteries are generally employed. A loud-ringing bell of the same construction as the telephone is supplied separately, as it is usually fixed away from the telephone.

In the latest model by the same makers (Fig. C6) the case is of enamelled cast iron with a door of special design without hinges, and arranged so that the whole instrument is absolutely proof against water, moisture and explosive gases. Accommodation is made for two dry cells in a part of the case, which is separated from the apparatus by means of a cast-iron partition. The ringer has its gongs in a perforated chamber

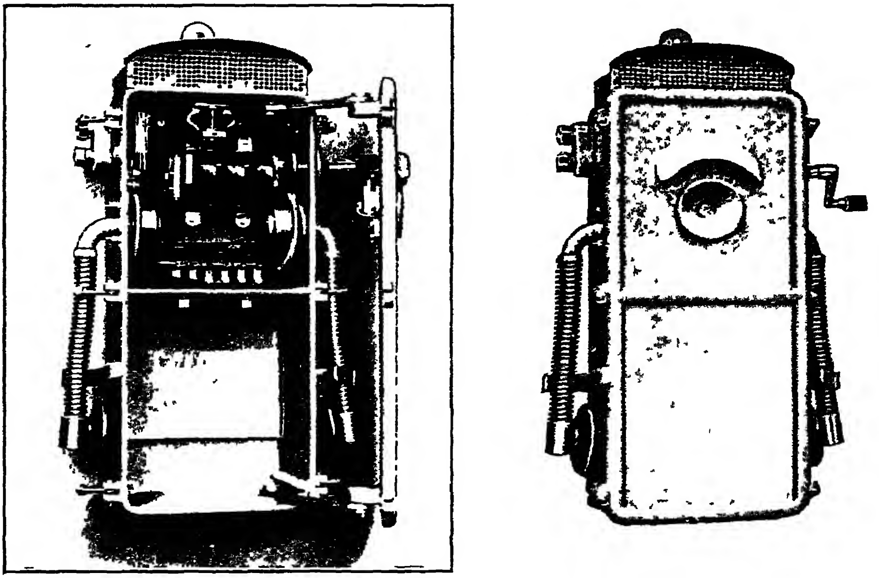


FIG C6 —Western Electric Co 's mining telephone set.

above the main case, so that a loud-sounding ringer is possible Two receivers are fitted inside the case, flexible metal tubes with vulcanite ear-pieces being led from the receivers outside the case. The set measures 23 in. by 6 in. by 12 in. and weighs about 54 lbs , it is specially suitable for use in mines, where simplicity of operation and reliability are required, where damp, corrosive or inflammable gases are likely to occur, and where instruments are likely to receive rough treatment.

CHAPTER IV

HAULAGE GEARS

Hauling.—The handling of the wagons in detail is done by hand, by pit ponies, or by small haulage sets, and when long distances have to be travelled the wagons are assembled at centres on main haulage roads, whence they are brought to the shaft by endless-rope haulages or in trains or "journeys" by large haulage engines.

There is no scientific line drawn between hauling and winding. Haulage roads are level or inclined at any angle, shafts at which winding engines work are vertical or inclined, or in some cases partly vertical and partly inclined.

In large pits the power of the haulage engine units is relatively small as compared with the power of the winding engine, but many haulage engines in large pits are larger than the winding engines in small pits, so that the classes cannot be divided either by duty or by size. Winding is generally taken as meaning the raising of the mineral to the surface in a vertical or highly inclined shaft, and hauling the transport of the mineral along more or less level roads. In winding the full weight of the load may come upon the rope, in hauling only a part of the weight, as the skips or wagons are always standing upon the rails.

Ropes.—On the Continent fibre ropes are largely employed, but in this country steel is almost exclusively used for haulage and winding ropes.

Reference to makers' lists discloses many qualities of steel called by strange or trade names, such as "Selected Extra Plough," "Improved Patent Crucible," "Patent Crucible," "Best Selected Bessemer," "Best Selected Charcoal." The names mean a great deal when applied to any particular maker's goods, otherwise they are merely conventional signs, and it is difficult to ascertain exactly the quality of the material used.

Messrs. Latch and Batchelor state the approximate breaking strain of their various qualities of steel wire as under —

TABLE D1.

Approximate breaking load in tons per square inch.

Best patent steel	90 tons sq in.
Mild plough steel	100 ,, ,,
Best plough steel	110 ,, ,,
Special plough steel	120 ,, ,,
Extra special plough steel	135 ,, ,,

to which may be added for comparison, although they are not used in mining ropes,

Iron wire	40 tons sq in
Bessemer steel wire	50 ,, ,,

The term "patent" used in this connection refers to the drawing of tempered steel wire as originally carried out by Mr. James Horsfall, whose wire was used for protecting the earliest Atlantic cables.

Hardness or mere tensile strength must not be alone considered, as steel ropes harden in use, and a worn rope may give a higher tensile test than it did when new and unworn, although it cannot be considered to have been improved by wear.

More important than the tensile strength is the brittleness of the wire, as upon this, apart from frictional wear, the life of the rope depends. In haulage ropes particularly there is a temptation to make the drum and pulley diameters too small, so that the rope gets unduly bent in working The stronger, *i e.*, the harder, a wire is the less capable it is of withstanding bending. A log is sometimes kept of rope tests on the basis of the number of twists that a length of 8 in. of wire will stand ; a bending test would appear to be better, as more closely approximating working conditions if the radius over which the wire is bent was taken in proper relation to the size of the wire under test.

Tests of wire ropes made for Sir William Arrol by Mr. A. S. Biggart during the building of the Forth Bridge showed the life

of a rope $1\frac{3}{4}$ in. circumference on a $10\frac{1}{2}$-in. pulley was 16,000 runs when dry and twice as many when oiled A similar rope on a 24-in. pulley ran 74,000 times when dry and five times the number when oiled (*Proc. Inst. Civ. Eng*, Vol. CI.).

In the case of haulages, other than endless rope, the friction of the rope along the roads is the principal destructive agent; for this work steel ropes of about 80 tons per square inch breaking stress may suitably be employed, and in order to avoid large and unhandy drums it is good practice to have the drum diameter fifty to sixty times the rope diameter. In the case of electric haulages, as the maximum torque which the motor can exert is known, a factor of safety of 5 or 6 is ample. Locked-coil ropes are often employed as the wear is more uniform; a broken wire is kept in position by the peculiar locking section, and in this construction smaller wires can be used, which results in a more flexible rope.

Flattened strand ropes have a smoother outside surface and have a longer life than ordinary ropes, and approximate a locked-coil in some particulars.

Makers' tables of strength of ropes are based on the aggregate strength of the individual wires, and the working load is generally taken as from one-sixth to one-tenth of the breaking load.

An empirical formula for the strength of ordinary lay steel ropes of about 80 tons tensile strength with hemp cores is

$$C^2 \times 3 = \text{Breaking load in tons}$$

when C = Circumference of the rope in inches.

In ordinary rope-making yarns are made by twisting fibres together right-handed. Strands are made by twisting yarns left-handed, the rope being composed of strands twisted right-handed with or without a core. It will be observed that in each succeeding step of the process the lay is reversed. Wire ropes are similarly made by twisting wires and strands in opposite directions. In Lang's lay the rope is made up by twisting strands in the same direction as that in which the wires forming the strand are twisted; this results in a better bedding of the wires, and a larger exposed surface with greater flexibility for the same size of wire.

In working endless-rope haulages the handling of the clips or chains is apt to be very severe on the rope, hence it is better to use a hard or plough steel quality, and as an ordinary lay presents a rougher surface it affords a better grip than a Lang's lay, locked-coil, or flattened-strand rope.

For other haulages a softer grade of steel may well be employed, and it is well to employ the largest practicable wire, as it takes longer to wear through, even at the expense of some flexibility. The 1911 Act, s. 46 (1), calls for the re-capping of haulage ropes at least every six months irrespective of the amount of use to which they are subjected, or whether they are driven by an electric motor or a reciprocating engine.

Ropes should be oiled where possible, as their life is increased if the wires are mutually lubricated. Judgment must, however, be exercised, as an oiled rope may pick up more grit than a dry rope, which will increase the wear of the rope on the drum.

For use in the presence of corrosive gases or bad water the ropes should be protected by galvanising, but such treatment renders the steel more brittle and weakens the rope, hence a larger and heavier rope is required for the same factor of safety, so galvanising can only be looked upon as a necessary evil.

Types of Haulage.—Haulages may be of the single drum type, when they are worked with a single rope, or of the double drum type, when they are used either for two main ropes or for a main and tail rope. In this case both the drums can be either driven by the shaft or can free-wheel on the shaft. The third variety is endless rope haulages, in which case one or two turns of an endless rope are taken round a specially grooved friction pulley to ensure sufficient grip to drive it. In some cases a chain instead of a rope is used for endless haulages.

Until the last few years all the above types of haulages were worked either by compressed air or steam engines. In some cases the steam engine and gearing complete were fixed on the surface and the ropes taken down the shaft. This was to meet the objection of taking steam pipes down the shaft or having steam boilers under ground.

Electricity offers so much greater convenience, power, and economy, that its use for main haulage engines is becoming very general. The prime cost of an electrical haulage is high as compared with the cost of compressed air or steam gear, but if it is of good design and workmanship the maintenance is very small and the life promises to be long, so that the investment is a profitable one.

The normal power of a steam or air haulage can only be exceeded by some 25 per cent overload under favourable conditions, but in a mine the loss of pressure in the pipes frequently prevents even the rated load being obtained. In an electric haulage the normal rating can be exceeded by 100 per cent. for short periods, while the starting torque is some two to two-and-a-half times the normal, which is a very great advantage quite apart from the economy in working.

In the case of electricity the power is always available without any delay, so that by merely turning a switch an odd journey can be run at any time without waiting for condensed water to be drained out of pipes. The steady starting and hauling of the wagons decreases the amount of mineral shaken out of them on to the roads, or otherwise broken, and also prolongs the life of ropes, shackles, and wagons. Every haulage motor should be provided with an ammeter in front of the attendant, as it serves as a valuable indication, not only as to the working of the machine, but also as to the state of the road, and so promotes better maintenance of the roads. These are important points which are appreciated by the mine managers who have experienced them.

While extolling the virtues of electric haulages the author would not recommend their universal adoption, as the result of taking electricity into some places may cost more than any possible saving, not only in capital outlay, but also in the disturbed peace of mind of the management and men. There will always be a field of usefulness for compressed air haulages in gassy mines and places outside the safe sphere of electricity. Fortunately, haulages in such situations are nearly always of small size, in fact 25 to 50 h.p. used to be practically the maximum for underground working by compressed air. The

introduction of electric haulages has made 200 to 500 h.p. sets quite common.

The facility and economy in speed regulation of the continuous current motor is unfortunately discounted by the presence of a commutator, and the greater economy in transmission of high tension three-phase energy has made three-phase haulages more common than continuous current, in spite of some of the drawbacks attending its use

Discredit has been done to electric haulage in some quarters by the poor quality of the work put into both the electrical and the mechanical parts. The fact that an electric motor will give a much greater torque than a steam or air motor of the same rating has not been appreciated as it should have been, with the result that many old steam or air haulage sets have been converted and fitted with electric motors too large for the gear, which was then found to be too light to stand the strain, and suffered excessive wear and tear, if not actual breakdown, so that the conversion of old machines has often been false economy

Experience has shown that both the beds and gearing for electric haulages must be more heavily constructed than the corresponding parts of steam or air driven haulages of equivalent nominal power.

The facility with which electric haulage sets can be handled, and the high torque at low speeds, enables the management to use a haulage gear to clear a road after a runaway has occurred. Experience has shown that the road is cleared considerably quicker if a hook is attached to a tangle of wagons and the heap drawn out by the haulage than if it is cleared with hammers, chisels and axes, as it had to be before powerful electric haulages were available.

Not only must the motors and gearing be of robust construction, but the controllers must be equally well built. Controllers of the tram-car type, or liquid resistance switches, were commonly used. The author has always refused to adopt these types, as he has held that the extra cost of the heavier resistances and switches was money well spent. Seven years' experience with sets in daily operation has confirmed this opinion. He still holds that neither motor, controller, nor gear should have

anything flimsy about it, but everything must be designed on unusually liberal lines and thoroughly well fitted, when success follows.

In general arrangement the haulage gear should occupy as little space as possible consistent with the conditions above detailed, with the addition of ready accessibility in the event of an accident. The gearing, as mentioned, should be liberally designed. Some of the earlier makers, especially in the case of converted steam sets, preferred to have the haulage gear apart from the motor and to drive by ropes More space is occupied, a certain amount of shock is taken off the motor owing to the flexibility of the ropes, and the motor may be of a higher speed. It is now more usual, however, to couple the haulage gear direct to the motor.

GEARING.—Worm gear, straight spur, and double-helical gear have all been used for the purpose. The author has generally adopted straight teeth, as he held the opinion that, due to the uncertainty of the foundations and their liability to settle, a strain might be put on the gearing which by added friction would discount the advantage of the double-helical arrangement, although he thoroughly appreciates that where everything can be kept rigid the more elaborate gear can give excellent service. In cases where elimination of back-lash has been important he has used, with complete success, two wheels side by side keyed on half a tooth out of pitch ; the rolling contact is then practically continuous, with the advantage that some side motion is permissible. For moderate reductions and low speed clean cast machine-moulded gear gives excellent results, and the hard skin on the teeth ensures long life, but now that cut gearing can be obtained at a moderate cost the matter requires further consideration.

In transmitting rotary motion and power from one shaft to another by means of gearing the aim must be to do so at an even angular velocity without shocks and without setting up vibration.

It is generally expected that gearing should be highly efficient, that it should be economical in first cost, and not be subject to undue wear.

Straight Gear.—Not all these conditions are fulfilled by

straight-cut gears, even when accurately made of true involute shape.

In the engagement of teeth three distinct phases occur—the phase of approach when the root of the pinion engages with the top of the tooth in the wheel, during which period the maximum stress occurs on the wheel teeth, and during which period a certain amount of sliding takes place between the two engaging surfaces; the second phase, when the teeth engage near and on their pitch line, when the motion is approximately a true rolling one; and the third phase, when the top portion of the pinion teeth engages with the lower pinion of the wheel teeth, during which period the maximum stresses occur on the pinion teeth, and again a certain amount of sliding takes place.

It will be noticed that when the stresses on the teeth are greatest the power is transmitted by portions of the teeth between which sliding friction occurs, so that naturally a certain amount of wear must take place. Such wear cannot take place without to some extent altering the shape of the teeth from their true involute form. Uniform angular velocity can only be maintained so long as the teeth retain their true involute shape; therefore slight variations of velocity will occur as soon as wear has set in, although the variation may be very small. It must further be observed that a tooth during each engagement is subject to a great variation of stresses, the frequent repetition of which must have an effect on the structure of the material, and probably to these frequent variations of stresses may be attributed the failures of accurately cut gearing under their normal working loads, which occur without any extraneous causes that could account for such a sudden collapse.

In order to effect transmission by gearing at as nearly as possible uniform velocity it is necessary to design the wheels in such a way that the following pinion tooth is in engagement before the leading tooth comes out of engagement. With fixed diameters of pinion and wheel these conditions can only be obtained with a suitable number of teeth in the pinion. This condition of continuous contact, therefore, practically determines the largest pitch which can be used with gears of

fixed diameters If the pitch required for certain working conditions does not fulfil this condition, it becomes necessary to increase the dimensions of the gear.

To sum up. the defects inherent to the best type of cut spur-gearing are—the continuously varying phases of engagement combined with continually varying stresses on the teeth, and the difficulty in obtaining continuous contact with the pitch and diameters most suitable to meet certain requirements.

These inherent drawbacks of the system make it impossible to obtain a really silent straight-cut spur-gear ; they cause a certain amount of loss in efficiency , limit the velocity up to which such gear can be used , and sometimes cause sudden breakages on heavy loads, whatever the material used for the gears, owing to their deterioration due to varying stresses, and necessitate pinions with a minimum number of teeth of about twelve, which cannot be reduced if anything like a satisfactory gear is expected. The limitation of the number of teeth in the pinions at the same time restricts the ratios of reduction which can be obtained.

By putting together gears consisting of extremely thin laminations in such a way that the first and last lamination are stepped half the pitch, and by making the single steps infinitesimally small, a helical tooth is obtained as the rational development of the stepped tooth to its extreme limit. Such a tooth possesses quite a number of interesting and valuable properties, but it also possesses one drawback, viz., that there always is a component of the power acting normal to the tangential tooth pressure, and exerting a pressure on the tooth in the direction of the axis. In order to equalise this side pressure a right-hand and left-hand helical tooth of equal width are generally used on the same wheel

Double-helical or herring-bone gears with right-hand and left-hand teeth have properties which differ favourably in essential points from those of straight-cut gears. Such gearing was first suggested by Dr. Hooke, and has been made for many years with moulded teeth.

The difficulty originally experienced with double-helical cast gear was due to the lack of means for machining it and the difficulty in trimming it accurately, in addition, of course, to

the high cost of hand trimming. The gear was never obtained quite true, so that it had to be run with the apex of the V leading. The greater accuracy of machine-cut gear gives more reliable contact, but due to the difficulty in timing the point of reversal or change of direction of the cutting tool it is extremely difficult, if not practically impossible, to ensure absolute accuracy in the teeth of double-helical gear. The teeth are stiffest at the apex of the V as the one tooth supports the other, consequently the wear is concentrated at these points. The engagement is fairly true, and the wheels run quietly so long as the apex leads ; but if an attempt is made to run the gear in the reverse direction these inequalities are apt to be very evident, and are exaggerated by any slackness in the journals. Machine cutting also enables the dimensions of such gear to be reduced as compared with those of moulded gear.

The difficulty in machine cutting has now been overcome by the Power Plant Co. and other makers, who claim that machine-cut gear is now so cheap that the use of moulded gear may be compared to the use of rough castings in journals.

The different phases of engagement which have been described for straight teeth do not occur in helical teeth The line of engagement can never lie right across the tip of the tooth, but always runs on a spiral line across the tooth surface. *i e.*, different phases of engagement occur on each tooth at any one moment. The result is an average engagement, which varies very little from engagement on the pitch line, whereby the variations of stresses become a minimum and periods of sliding and rolling contact do not alternate, but at any moment rolling contact on or near the pitch line, as well as a certain amount of sliding contact on the top and bottom portion, takes place simultaneously.

Without going into the question of the relative absolute strength of straight and helical teeth respectively, it can therefore be definitely stated that a tooth of helical form of smaller pitch will do the same work as a straight tooth of larger pitch, because the maximum stress on the helical tooth is only about equivalent to the mean stress on the straight one.

The absence of stress variation, and the absence of alternating sliding and rolling contact, cause a marked improvement

in efficiency, and prevent any change of angular velocity. Such gears run, therefore, silently at the highest velocities.

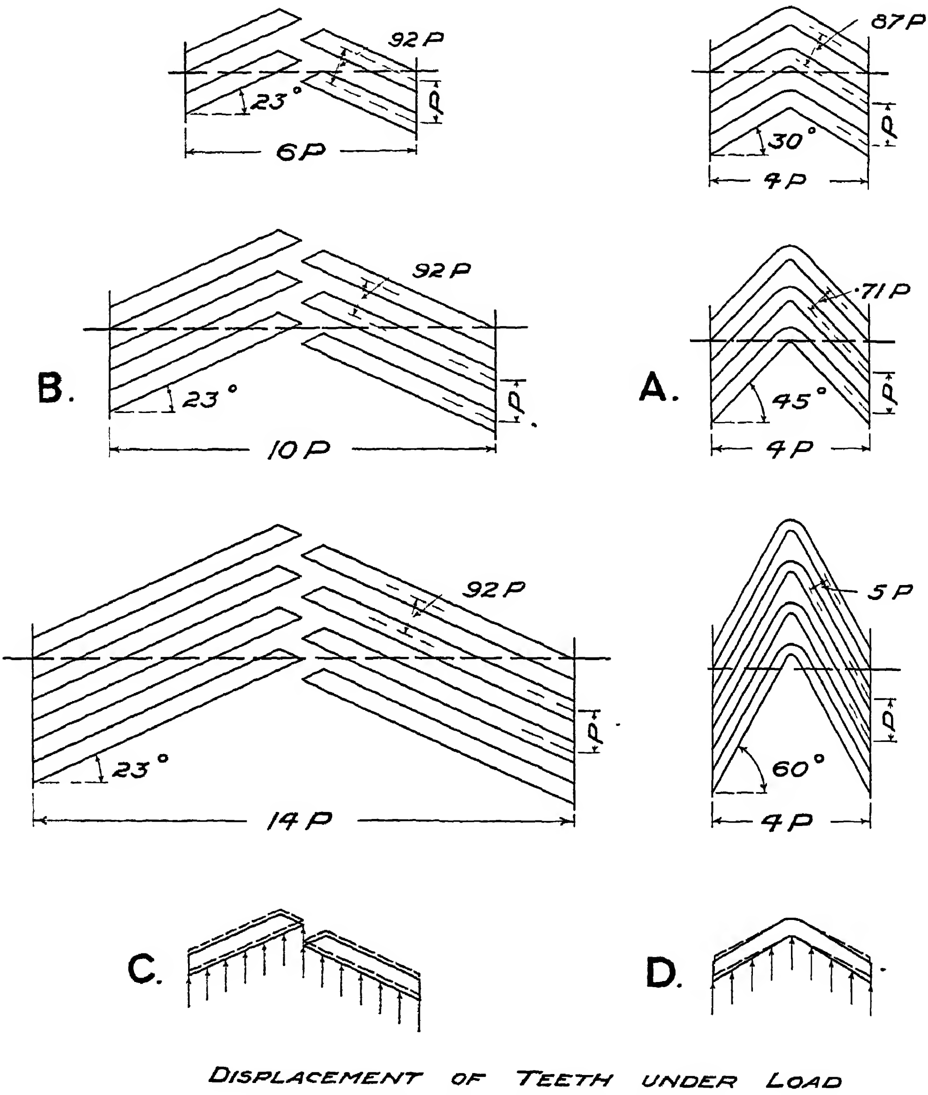


FIG. D1.—Double-helical gear teeth.

Whilst in straight-cut gearing the amount of wear at the top and bottom of the teeth, owing to the sliding friction under

which the maximum load has to be taken, may become considerable, in double-helical teeth, the sliding and rolling contact phases being in engagement simultaneously, there will be a tendency, by the slightest amount of wear on the top and bottom portions, to concentrate the load nearer to the pitch line where transmission is effected practically without any sliding; and it has been found in actual practice that after extremely slight wear on the portions mentioned—too small to be of any practical consequence—the gears will not alter any further, and will work without wear, provided that all the dimensions are chosen as they should be

It will be remembered that it has been shown that in straight-cut gearing continuity of contact was dependent on the number of teeth in the pinion. This is not the case in double-helical gears, and it will be apparent from Fig. D1 that there are two ways in which it is possible to bring (within certain limits) as many teeth in simultaneous contact as desired, and thereby to distribute the load in the most suitable manner.

One way to bring a number of teeth in engagement is to increase the angle of the helix, the other to increase the width of the gear. The first way (A), however, must be used with extreme caution, and only within certain limits as it has a number of distinct drawbacks, one of which is that with increasing angle a tendency to wedge action is caused, another that, whilst the transmission of load has to be effected at right angles to the direction of the tooth, the normal section of the tooth becomes weaker as the spiral angle is increased. The second way (B), the increase of face width, can, however, be carried as far as practical necessities demand. By increasing the face width of a double-helical gear, and distributing the load over a large number of teeth, it is possible to transmit very heavy powers with comparatively fine pitched gears, and to keep the pinion diameters as small as desired; in fact, the smallest pinion diameter (face width not being limited) is no longer determined by any minimum number of teeth, but only by the diameter of shaft required to transmit the given power, the pinion pitch diameter may be made so small that the diameter of the root circle of the teeth coincides with the shaft diameter. Double-helical gears in practice are only limited in

ratio of reduction by the largest diameter of wheel which can be conveniently accommodated, the desired contact conditions being always obtainable by suitably choosing the pitch and face width of the gears.

The characteristic advantages of double-helical gears are therefore :—

First, teeth practically under uniform stress, eliminating the dangers from stress variations and increasing the power-transmitting capacity of the gears

Second, teeth under uniform conditions of rolling and sliding contact, resulting in a minimum of wear and maximum of efficiency.

Third, continuity of contact entirely independent of the number of teeth in the pinion, rendering the highest ratios possible in single trains of gears. Silent running without shocks and vibration is the result of these three characteristic features of double-helical gears combined.

The above advantages are those theoretically belonging to double-helical gears. It is obvious, however, that the realisation of these advantages depends to a very large extent on the process of manufacture, because they are only obtainable with correctly shaped teeth.

Two types of double-helical gear are commercially available at the present time .—

One type with the right-hand and left-hand teeth joined in the centre (Fig. D1, A).

Another type (Fig. D1, B), with the right-hand and left-hand teeth not joined in the centre, but displaced with reference to each other by half the pitch.

The first type can at the present time only be produced by means of an end-milling process, which requires milling cutters of varying diameter at the top and bottom which have to be formed to template This process has certain defects which it appears hardly possible to eliminate.

Gears with right-hand and left-hand teeth displaced by half the pitch are called Staggered Double-Helical Gears, and have become widely known under the name of *Wuest* gears, the name of the inventor, or of " P.P. " gears, the trademark of the Power Plant Co., who are the English

manufacturers. Such gears can be produced in a variety of ways.

It has been suggested that double-helical gears with staggered teeth are not so strong as end-milled gears with continuous teeth. This suggestion is based on the mistaken assumption that strength is an important factor in the calculation of double-helical gears. In practice consideration of wear determines the dimensions of high and medium speed gearing entirely, and results in tooth proportions with safety factors between 10 and 20 ; *this is a much higher factor than is usual* for parts of machinery the dimensions of which can be based on calculations.

On the other hand, staggered teeth are more uniformly stressed than continuous teeth, their resistance against bending being practically the same over the whole width, whilst continuous teeth offer more resistance in the centre than at the side, resulting in a concentration of load towards the centre portion, which is evidenced by increased wear at that part (Fig D1, C and D).

Gearing is likely to play a much larger part in the future than in the past, not only in mining work, but in rolling mills and other heavy work, as well as in the marine service. Great strides have been made lately in the adaptation of gearing as an economical link between a turbine and a screw-propeller. Sir Charles Parsons has claimed a loss of power in the new double-helical gearing of only $1\frac{1}{2}$ per cent. Such results depend not only on accuracy of workmanship, but also on lubrication. Any foreign matter in the oil which causes an uneven distribution of the pressure may, however, have disastrous results.

Endless Rope Haulage.—In this type a double road is used, one track carrying the outgoing, the other the in-bye traffic. The rope or chain may be taken either over or under the wagons, which are attached to it by a clip or chain, and is kept constantly running at from one-and-a-half to two miles per hour.

The wear and tear at the low speed of travel is very small, both as regards wagons and track. In coal mines it is favoured

on account of the decreased dust as compared with systems where the wagons are moved at high speeds.

Another advantage in an endless rope haulage system is that there is a steady and continuous flow of wagons. The power required is considerably less than for a main haulage and is nearly constant, and on an incline the weight of the wagons cancels out, so only the weight of the mineral has to be considered.

There is, however, some difficulty in working round curves

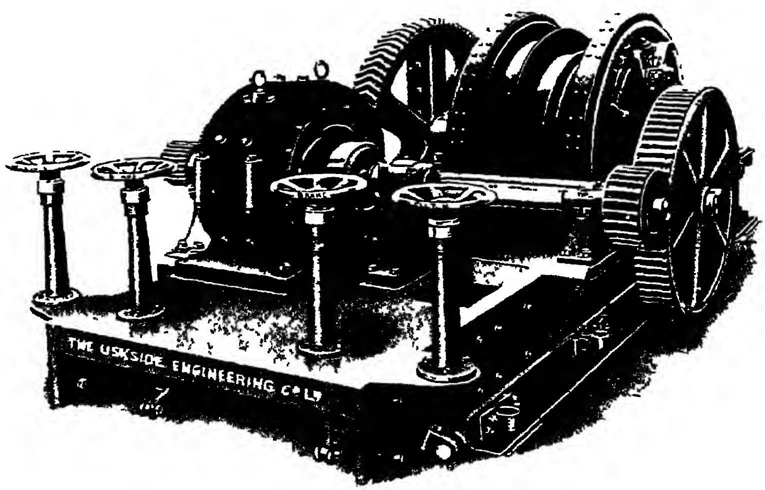


FIG. D2.—Double endless rope haulage gear.

on account of the extra guide pulleys which are then necessary. The system is most suitable on straight and fairly level roads, as in the event of a down grade the wagons over-run the rope unless attached by a friction grip, which is more trouble than the usual bent claw which is employed when the rope is over the wagons.

Fig. D2 shows a double pulley haulage gear of the treble reduction type suitable for a rope speed of one-and-a-half miles per hour, and has two cast-iron pulleys with renewable wearing treads, mounted loose on the drum shaft, and operated through external band friction clutches of the Uskside Co.'s

own manufacture. The main gearing is of cast iron with double-helical teeth. The second motion wheel is of iron and the pinion of steel with plain machine-moulded teeth. The first motion gearing has plain machine-cut teeth, cast steel wheel, and forged steel pinion. The gear is of heavy design throughout, is entirely self-contained, and carried on a built-up rolled steel bed-plate, consisting of plates and angles, strengthened with deep cast-iron cill-plates, attached to the sides with turned bolts. On haulages with frames of this type a heavy cast-iron bed-plate is bolted between the frames to ensure rigidity. This casting is extended and carries two clutch and two brake hand wheels. It will be noticed that one of the pulleys is a double one, as an auxiliary rope was required to drive a pump. The main pulley is 6 ft diameter, the other two are 5 ft diameter. This is the usual type adopted for working two districts , each pulley is separately clutched, and the motor runs continuously

Single-Drum or Main-Rope Haulages are only used to pull a load up an incline, which must be at least 2½ in. to 3 in in the yard to ensure that the empties will run back by gravity taking the rope with them.

Sometimes several drums for such haulages are worked off one main shaft which runs constantly, the drums being connected to it through friction clutches for hauling and free-wheeling on the return journey. The worst objection to this arrangement is the sudden strain which is thrown on the rope at starting by the almost instantaneous acceleration to full speed. Some slip may be allowed by skilled handling of the clutch lever, but this only removes the wear and tear from one point to another without overcoming the objection, hence the arrangement is not convenient for high speeds.

Another method of meeting this disadvantage is to start the full trucks down a slight incline, which is also advantageous in bringing the empties to rest.

The usual rope-speed for such haulages is six to eight miles per hour, although in the case of large haulages with long runs a speed of ten miles or upwards is attained.

Double-Drum or Main-and-Tail Haulages are the most common, and may be used either as two single or as a main-and-tail, in which case the main rope hauls the load, to which the tail rope is attached, it being led round a pulley at the far end of the line, and is drawn off the tail drum by the loaded wagons. The tail rope is then available for drawing the empties back into the workings.

Fig. D3 shows a 100 h p. double reduction haulage, which was built by the Uskside Co. to meet special conditions at the Ferndale Collieries, where the braking was very heavy owing to full journeys having to be let down an incline. The drums,

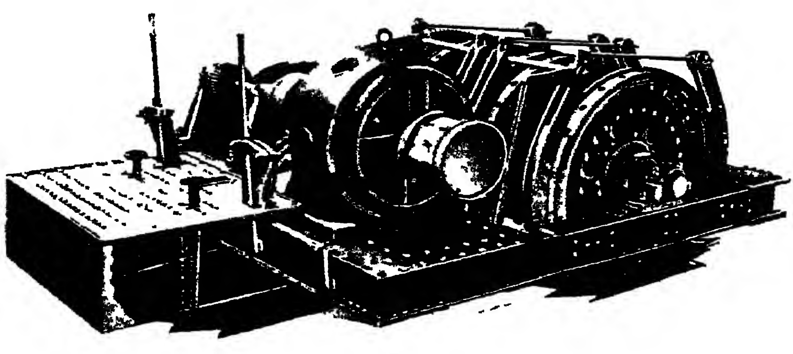


FIG D3.—100 h.p. "Uskside" double reduction haulage.

which run at 36 r.p m., are of the built-up type, 4 ft. diameter 2 ft. wide, by 1 ft. deep, and have solid cast-iron centres and tread, rolled steel-plate cheeks, cast-steel clutch piece, and a brake ring on both sides of the drum with renewable curbs. To meet the unusually heavy braking conditions called for, this particular haulage was fitted with double post-brakes on the drums, also a brake on the first motion shaft. All the gearing is of steel, the main gearing having heavy machine-moulded plain teeth, the first motion having machine-cut plain teeth. The drive is taken from the motor through a flexible coupling. The whole of the gear is self-contained and mounted on heavy rolled steel bed-plate. The motor is of the semi-enclosed type, 2,200 volts, three-phase, 25 cycles, with a

synchronous speed of 375 r p.m , and provided with enclosed slip-rings.

Fig. D4 shows a single reduction haulage gear capable of an output of 320 h p. with a motor running at 290 r p.m. The drums are 4 ft. 6 in. diameter by 2 ft. 6 in. wide, and are built up in halves having cast-iron centre boss, cast-steel renewable clutch pieces, rolled steel-plate cheeks, and rolled steel-plate lagging attached to angle rings and cast-iron brake rings. The

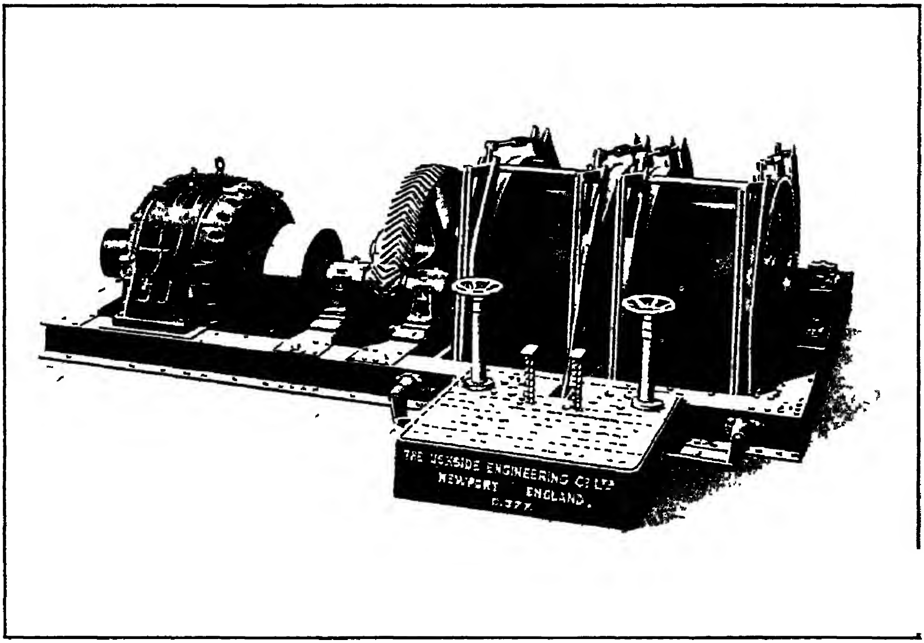


Fig D4 —320 h p single reduction haulage

drums are mounted loose on the drum shaft and operated through separate steel jaw clutches by hand wheels. The brake gear is particularly heavy in design, as the haulage was used for a rubbish tip, where the amount of braking is considerable. The brakes are of the double post-type operated by a foot lever. The haulage is geared through double-helical machine-cut gearing, single reduction, with a ratio of 8 to 1. The gear is of steel. The pinion has nine teeth, and is cut out of the solid with the shaft. The gear wheel has seventy-one

teeth, 3-in. pitch, and is 11 in. on the face, the angle of the teeth being 45°. The pinion shaft is carried in ring lubricated bearings and driven from the motor through a flexible coupling of the Uskside Co.'s own type. The gear is self-contained and erected on a heavy rolled steel girder bed-plate, all the operating levers being brought to a convenient position on a cast-iron bed-plate.

An interesting point arose in the working of this haulage.

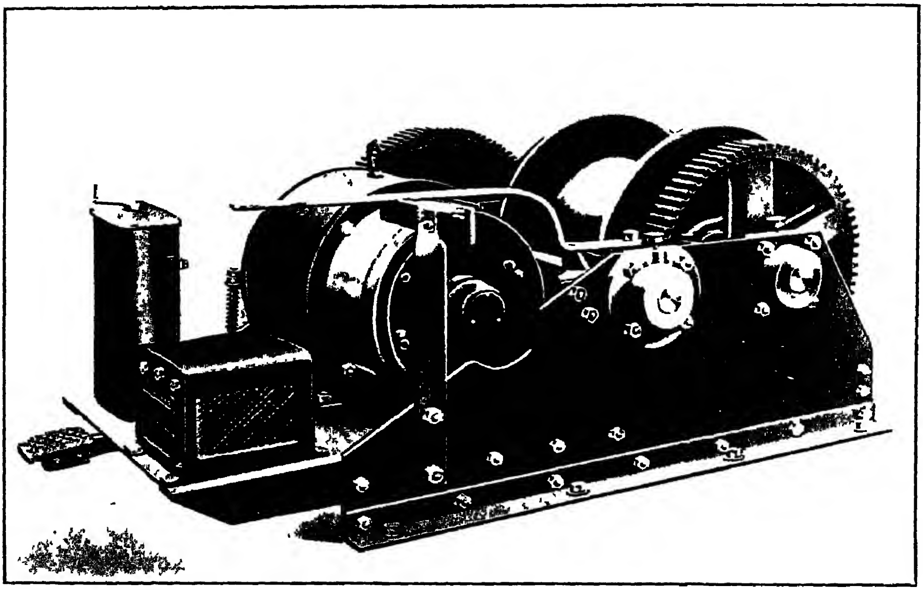


Fig. D5 —" Uskside " 25 h p. portable haulage

Soon after it was started extraordinary vibration at about one-third load was noticed, the rope being taken off the top of the drum and one drum only being in use. The vibration was set up through the whole haulage and was sufficient to throw any loose parts, such as lubricator caps, &c., on to the floor. The vibration always commenced at the same point, *i.e.*, about one-third load, and as soon as this was passed and one-half load reached it gradually ceased. The Power Plant Co., who made the gear, claimed that it was no fault in the gearing, and suggested that if the rope were taken

off the bottom of the drum the vibration might be stopped. This was tried, and the vibration trouble at once disappeared. It will be noted on reference to the figure that if the rope is taken off the top of the drum the pinion is not running with the apex leading, but is running backwards. This is a possible disadvantage in double-helical gear, which, of course, frequently is made and has to be used for reversing. When it is run apex first the wheels tend to pull themselves into position and to atone for any slight inequality or want of adjustment in the bearings, but if it is run backwards this self-righting property is lost and any want of adjustment in the bearings is accentuated.

Portable Haulage.—Fig. D5 shows a haulage of a type recently introduced by the Uskside Co. It is very compact and handy, and offers special facilities, as it is entirely self-contained and has nothing projecting below the bottom angle of the framework Such haulages may be very usefully employed to collect wagons to make up trains to feed main haulages, and may advantageously be used in many places where pit ponies are now employed. They are very easily transferred from one place to another as required, and call for little or no foundation. The single drum is of cast iron keyed to its shaft and driven through double-reduction machine-cut gearing. In order that the drum may reverse without the motor the main pinion is free to slide on feathers and can be disengaged by the clutch handle. The brake gear is of the band type, and is operated by a foot lever. The frame is entirely of wrought steel, and has an extension to carry the motor controller and resistance. Such haulages are arranged for a rope speed of about four miles per hour.

Standardisation.—When arranging for the equipment of the Ferndale Collieries it was decided for the sake of convenience, and in order to keep down the number of spare parts, to standardise the haulages in three sizes—200, 100 and 50 h.p. respectively. In the case of the 50 h.p. haulages (Fig. D6) double-reduction gear was used. In the larger sizes single-reduction was generally used (Figs. D7 and D8), although there

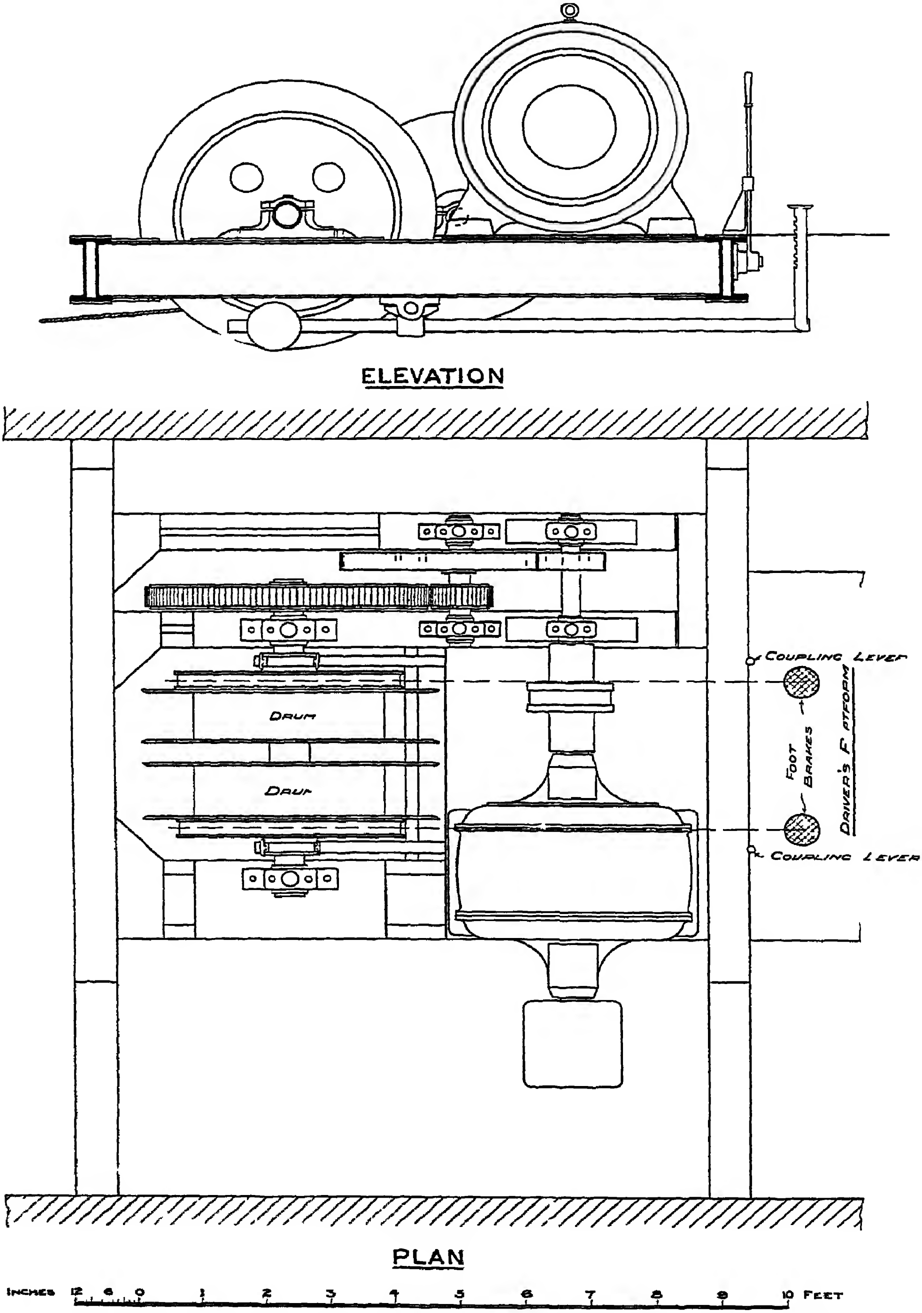


Fig. 96.—50 h.p. haulage, double reduction, fixed over the road.

were exceptions, one of which is shown in Fig. D3 above. Other sizes were made for special purposes. Leading particulars of the three standard sizes will be found in Table D2.

TABLE D2.

Size of haulage	50 h.p	100 h p	200 h p.
Drums (diameter of tread)	3 ft.	4 ft.	4 ft.
Drums (width of tread)	10 in.	2 ft.	2 ft.
Depth of flange	10 in	1 ft.	1 ft.
Length of rope (yards)	1,250	1,100	1,500
Weight of rope (lbs. per yard)	$1\frac{3}{4}$	$2\frac{7}{8}$	$4\frac{7}{8}$
Diameter of rope (inches)	$\frac{11}{16}$	$\frac{3}{4}$	1
Clutch (type)	Cast steel, positive jaw.		
Gearing	Cast steel		
Gearing (teeth)	Machine moulded, double shrouded to pitch line		
,, (pitch width)	2 in by $3\frac{1}{4}$ in	2 in by $6\frac{1}{2}$ in	$2\frac{1}{2}$ in. by 9 in.
Ratio	16 to 1	5 to 1	5 to 1
Shaft (diameter in bearings)	$3\frac{3}{4}$ in.	$5\frac{1}{2}$ in	8 in.
Plummer blocks	Cast iron with gun metal bearings		
Rope Speed (m.p h)	4	6	6
Rated b h p. of motor	50	100	200
Volts	2,200	2,200	2,200
Frequency	25	25	25
R p.m. at full load	485	182	182
Max peripheral speed in ft. per sec.	51 5	51 2	56
Air gap in mms.	1 5	1 75	2
Efficiency (full load), per cent.	89 5	88 5	90
Efficiency (half load), per cent.	87 5	88	87
Power factor (full load)	0 86	0 88	0 91
,, ,, (half load)	0 74	0·79	0 81
Max. torque in ft.-lbs.	1,034	5,540	11,080
Temperature rise after 8 hours' full load	70° F.	70° F.	70° F.

The special arrangement of the single reduction motor alongside the drums instead of behind them was adopted to meet the requirements of the Ferndale management, as if a large slow-speed motor were placed behind the drums it prevented the engine-man seeing his ropes. The drum was therefore placed at the side of the gear and connected to it through a flexible coupling which would accommodate any slight inequality or settlement in the foundations. This coupling

also has another important function, as its introduction in a geared haulage set prevents the vibration of the gearing

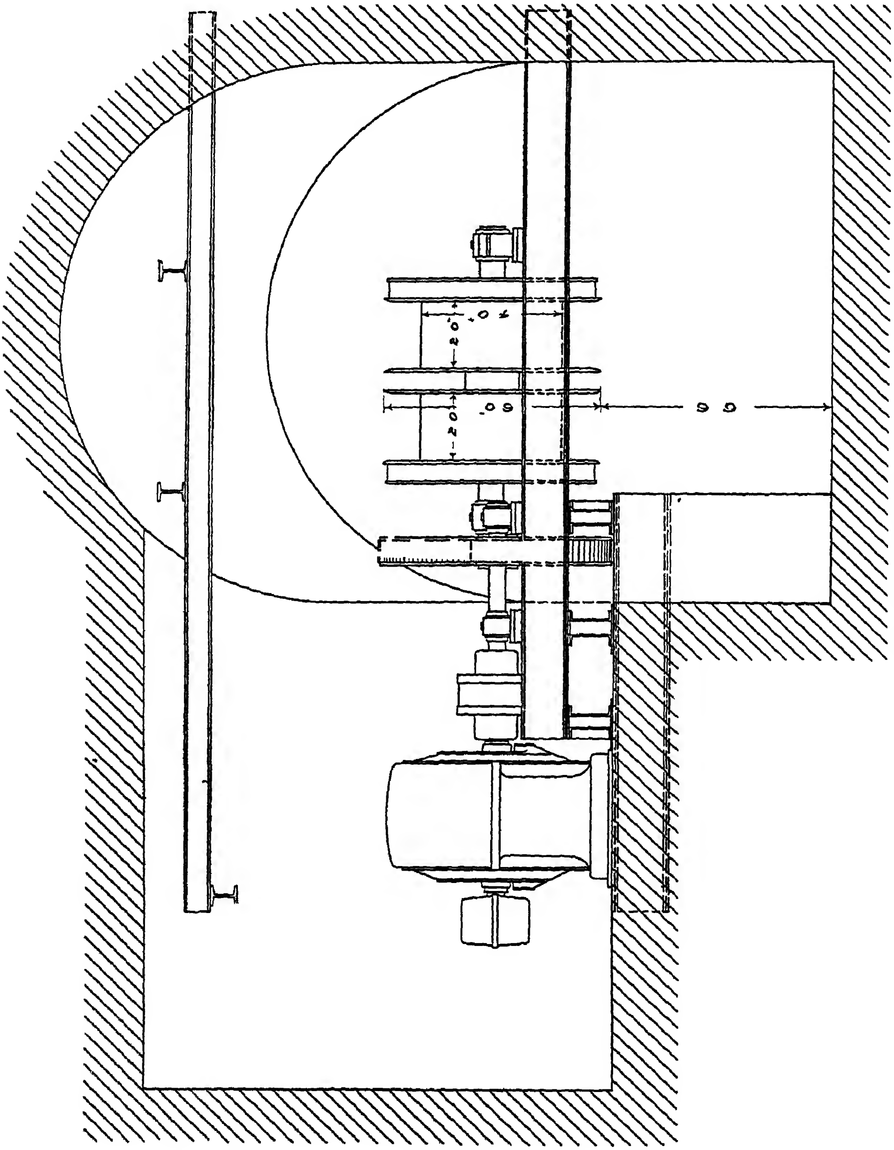


FIG. D7.—200 h p. haulage, single reduction, fixed over the road.

being transmitted to the motor. There are several types of flexible coupling; in the type adopted for the haulages shown the design approximates that of an ordinary claw-

clutch, with the difference that the claws are faced with heavy indiarubber blocks. Each half of the coupling is made in two parts, so that it can be removed and replaced without dismantling the shaft. These couplings have now been in use for several years and none of the rubber blocks have required renewal. The first motion shaft is sometimes provided with a brake, which proves of considerable convenience in handling and reversing the motors. The gearing is of cast steel. The drums are generally of cast iron with steel cheeks and renewable cast-iron brake paths. The brake blocks are also of cast iron renewable in segments. This type of block was adopted to avoid the sparking which has occurred with wooden blocks. A wooden block is certainly more effective as a brake than an iron one, and if they were made of considerably larger area there would be no sparking, which is due to their being overloaded.

The leverage ratio from brake block to foot pedal of one of the 200 h p. sets is 1 in 114. Assuming the driver to weigh 154 lbs. (11 st.), he can produce an effective brake pressure of 14,900 lbs., allowing an efficiency for the brake mechanism of 0 85. This is equivalent to a braking force of $\frac{14,900 \times \cdot 25 \times 6}{5} = 4,500$ lbs. at the mean drum diameter of 5 ft., with a friction co-efficient of 0·25 (steel on cast iron), the diameter of the brake path being 6 ft.

Fig. D7 shows a 200 h p. haulage erected over the road, with a minimum clearance of 6 ft. 6 in. so that the loaded wagons can pass under it. In such a case heavy steel girders are employed, which may be either pinned directly into the brick arching or may be set in wall boxes, which gives greater convenience for adjustment.

Fig. D8 shows the elevations and plan of a similar haulage fixed on the ground. A reference to this figure will show several important details in addition to those previously mentioned. The three hand levers and three foot pedals by which the engineman controls the haulage are all conveniently assembled on a cast-iron bed-plate ; the left-hand lever actuates the clutch coupling of the left-hand drum, and near it is its corresponding foot brake ; the lever in the centre actuates the reversing

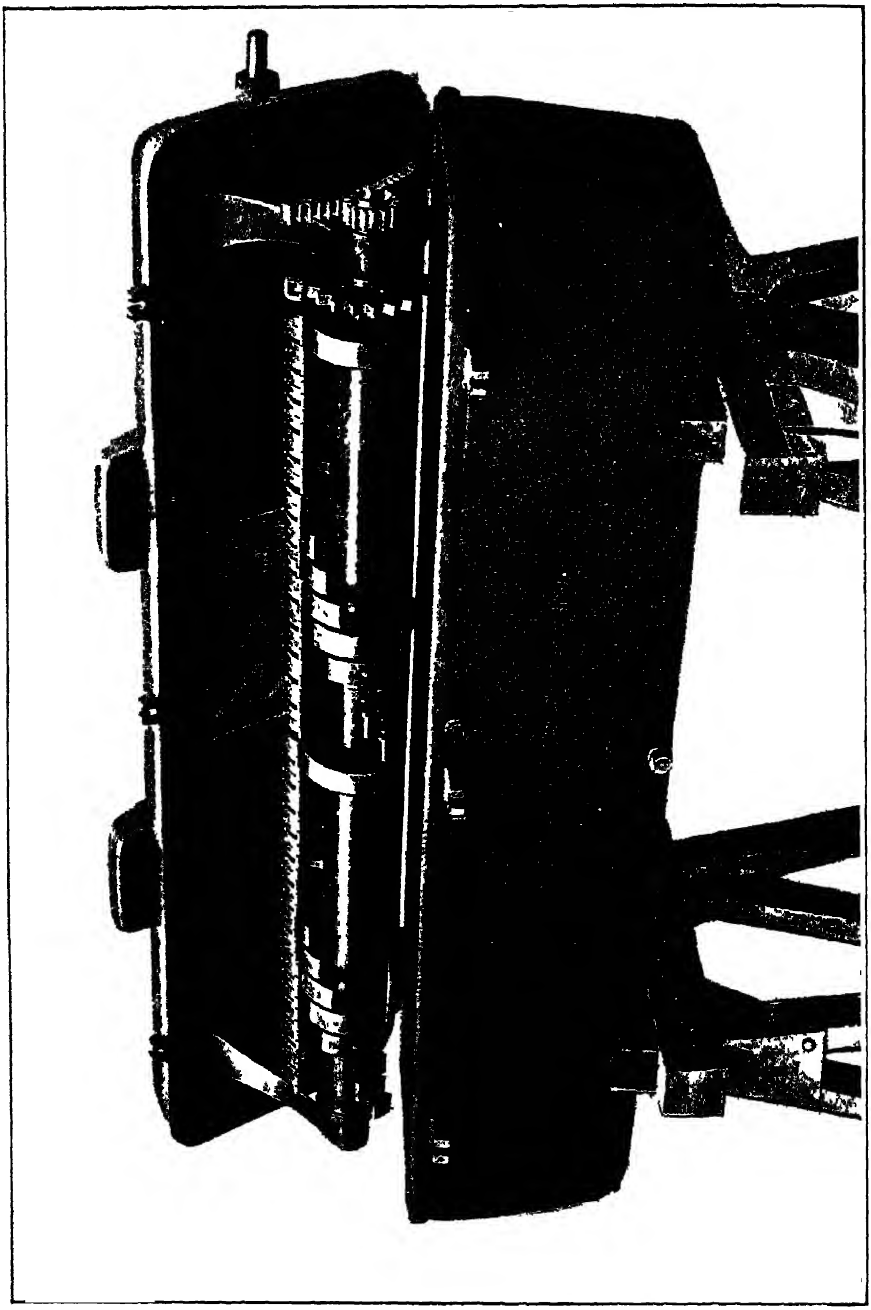


FIG D9 —Haulage controller.

switch and the controller; the right-hand lever actuates the clutch coupling of the right-hand drum, and between it and the pedal for the drum brake may be placed the lever for actuating the emergency brake on the first motion shaft. The weight of the foot brakes and levers is balanced by counter-weights, which are suspended from them by wires. Starting, reversing, and the speed control are all effected by movements of the centre lever. Behind the platform is the two-phase, oil

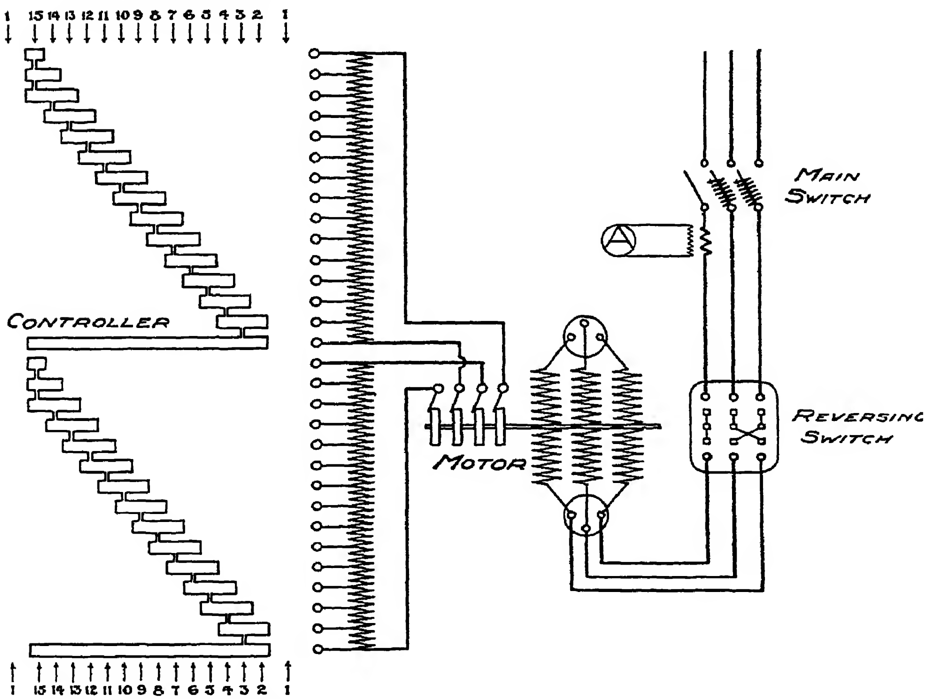


FIG. D10 —Diagram of connections to controller.

immersed, reversing switch, and behind it again is the controller drum, which is shown with the lid of the box open in Fig. D9. This is the first controller of the heavy type that was constructed.

When going into this question the author was of the opinion that neither the tramcar nor the liquid resistance switch such as had been commonly used were good enough for the work, and neither type was likely to give satisfactory results without considerable nursing and maintenance, which, unfortunately,

is not often obtainable under operating conditions. He therefore rejected the old types and in connection with Messrs. Lahmeyer evolved the type adopted, which they named "Patchell's system."

Fig. D10 shows a diagram of connections of the drum, switch, and resistances. The oil in the resistance boxes is circulated by a pump driven from the motor shaft, and is cooled by passing it through a set of gilled radiators, which in some cases are water-cooled. A rotary pump was employed, and in the first sets no non-return valves were put in the pipes, so that the pumps forced the oil in two directions, according to the rotation of the motor. This was found to be inconvenient, as in some cases the radiators had to be fixed at some distance from the haulages, and the result was that the oil practically moved from the radiator to the haulage and back without being thoroughly circulated. This defect was easily obviated by putting in a set of non-return valves, so that the oil was forced in one direction only, no matter in which direction the pump was driven. The amount of heat developed in a controller resistance will be dealt with later.

CHAPTER V

RATING OF HAULAGES

Rating of Haulages.—Although in each instance the haulage has to be considered in regard to its special work when several are required, as at Ferndale and other important groups of pits, it is not economical to design each haulage for a particular duty; standard sizes must be adopted. The tendency is usually to increase the load on a haulage, so that with a series of standard sizes it is safer to adopt the size larger than the calculations call for to meet the requirements at the moment.

The mechanics of a haulage are not difficult, but the varying conditions in the pit introduce so many variables in practice that close calculation is impossible. Although when full particulars are available a haulage problem can be worked out in the same way in which railway traction problems are treated, it hardly pays to go into such detail in practice, as the operating conditions in the case of a haulage are continually varying.

The weight of mineral to be handled per hour, or per day, can be determined, although this, of course, is never fixed but depends on the working; the number of trips to be run depends on the amount of mineral to be cleared.

The contour of the road and particulars of the curves are obtained by survey, but the condition of the road may vary from day to day.

A point which must not be overlooked in Main and Main-and-Tail Haulage is that the diameter of the drum increases with each layer of rope wound on it during the trip; consequently the torque and speed are increasing proportionately. For instance, with a 4 ft. diameter drum, having a width of 2 ft. and hauling from a distance of 1,500 yards with a rope 1-in.

diameter the speed of the rope when the drum makes 33 6 r.p.m. will be :—

At beginning of the trip	423 ft. per min.
At end of trip	633 ft. per min.

This means that on a level road the haulage is doing 50 per cent., more work at the end than at the beginning of the trip. In practice the "mean diameter" of the drum, *i e.*, diameter over drum and rope half-unwound, is generally taken to determine the speed and torque of the motor.

The position of the curves may also seriously affect the rating of the motor. The worst condition will be when a bad curve is coincident with the maximum gradient at the end of the trip.

Another variable is the friction of the rope, which may vary between wide limits, depending upon the condition of the road and as to whether the rope runs on pulleys or is dragged along the track. In some cases, as when 2,000 to 3 000 yards of rope are employed, the friction is so large as to be more important than the weight of the load and the friction of wagons. Then, again, all contingencies, such as derailment of trams, as previously mentioned, must be taken into account.

The above points emphasise the futility of attempting to fix the size of a haulage motor on purely academic lines. The only rational way to treat the problem is to put in a motor which will be large enough for the most onerous conditions of working. In other words, the break-down torque of the motor is the prime consideration.

Tractive Resistance.—Some time ago, in spite of the variables, the author thought it would be interesting and valuable to obtain some readings from actual tests by which existing formulæ could be checked, and carried out experiments upon a 100 h.p. single reduction haulage set with a drum 5 ft. mean diameter. Twelve loaded wagons were taken just as they came out of the pit for the purpose of the experiment :—

Weight of total load	48,400 lbs.
Weight of 12 wagons empty	12,300 lbs.
Useful load	36,100 lbs,

No. of wheels per wagon..	4
Diameter of wheels on tread	16 in.
Diameter of axles	2 in.
Gauge of track	2 ft. $10\frac{1}{2}$ in.
Width of rail-head	2 in.

The axle boxes were of the common type, open at the bottom, grease lubricated and fairly loose fitting. The line was practically straight with a gradient of 5° against the load, *i.e.*, 5·13 in. per yard.

The pull P was obtained by reading a dynamometer fixed between the rope and the first wagon.

With the load on the gradient at a speed of five-and-a-half miles per hour, *i.e.*, 8 2 ft. per second, P = 5,500 lbs.

P is made up of :—

p = weight component due to gravity, or W sin 5°,

p_1 = tractive resistance.

Inserting the values,

$$p = 48{,}400 \times 0{\cdot}08716 = 4{,}219 \text{ lbs.}$$

At such a low speed air resistance may be neglected, and the tractive resistance, *i.e.*, the friction of the bearings in the journals, and the friction of the wheels on the rails, is

$$p_1 = 5{,}500 - 4{,}219 = 1{,}281 \text{ lbs.}$$

From this is obtained the tractive co-efficient X, which is always dependent on the component of the weight acting vertically on the rails :—

$$1{,}281 = 48{,}400 \cos 5^\circ \text{ X}.$$

$$\therefore \qquad \text{X} = \frac{1{,}281}{48{,}400 \cos 5^\circ} = 0{\cdot}0265.$$

As the track upon which the trial was run was in better condition than usually obtains underground, it was thought safer to increase this result slightly and to round it off to 0·03.

From this can be established the following formula :—

$$\text{P} = \text{W} \times 0{\cdot}03 \text{ on a straight horizontal track,}$$

$$\text{P} = \text{W} \sin \text{A} + 0{\cdot}03 \text{ W} \cos \text{A} \text{ on a straight gradient,}$$

where A = angle of inclination of the track to the horizontal.

For small gradients up to 1 in 20 the value for the cosine may be neglected.

X_1 can be expressed either as a co-efficient 0·03 or as 67 lbs. per ton.

The trial was made on a straight track. The rope friction was not determined, as the dynamometer was placed between the end of the rope and the wagons ; nor were figures obtained for curves.

When these figures were first published and discussed (S. Wales Inst. Eng., Vol. XXVI), one speaker expressed surprise at finding the co-efficient so high (*ibid.*, p. 1133), and suggested that it was probably due to the weight, nearly two tons, being more than is usually carried on a pair of 2-in. axles. He stated that in many cases he had laid out roadways on a gradient of $\frac{5}{8}$ in. per yard for full wagons and $\frac{3}{4}$ in. per yard for empties, corresponding to co-efficients of 0·016 and 0·02 respectively, and in each case he found that the wagons moved by gravity. On a gradient of $\frac{7}{8}$ in. per yard, corresponding to a co-efficient of 0·024, he found that the wagons would accelerate and run away immediately they were started from rest. The same speaker also regretted that he had not been able to get any exact experiments as to the co-efficient of friction of a rope, but that he had arrived at a figure of 1 in 7, or, say, 0·143 of the weight of the rope under the usual conditions obtaining in underground haulage, including the friction and momentum of the haulage drum running free.

Motors.—Motors used for mining work should have non-hygroscopic insulation, principally of the mica type, and be specially impregnated, as, no matter how good the conditions may appear to be normally, accidents occur and the motor room may get flooded. Impregnated water-proof motors may now be thoroughly relied upon. Several instances have occurred where motors have been actually submerged, taken out, dried, and put to work without subsequent ill-effects. One of the worst cases on record was in a South African mine where motors made by the General Electric Co., Schenectady, were under water for two years, but subsequently taken out, dried, and put to work without having to be re-wound.

Rule 4 (5) of the Special Rules attached to the 1904 Report reads :—

"In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, all motors, unless placed in such rooms as are separately ventilated with intake air, shall have all their current-carrying parts, also their starters, terminals, and connections completely enclosed in flame-tight enclosures, made of uninflammable material, and of sufficient strength as not to be liable to be damaged should an explosion of fire-damp occur in the interior, and such enclosures shall not be opened except by an authorised person, and then only when the current is switched off. The pressure shall not be switched on while the enclosures are open."

This rule has been considerably debated and sometimes misunderstood. Attempts have been made to make a gas-tight motor ; such a thing is, however, practically impossible, due to the breathing or expansion of the air in the motor frame which must naturally occur and which must be allowed for. A void always occurs along the journals, but it has been considered better in practice and found more reliable to admit of the expansion by making the motor "flame-tight" rather than to attempt to make it "gas-tight." Various devices have been used, perhaps the best of which is the "plate protection," which consists of a series of thin plates arranged as gills through which the motor may breathe. This protection was developed in the course of some experiments in Germany which were started in 1903. In the following year further experiments were tried on various types of so-called fire-proof motors. Totally enclosed motors were tested, as also motors ventilated with gauze over the openings, labyrinth ventilation, tube ventilation, plate protection, and also oil-immersed motors.

"Plate protection" applied to a squirrel-cage motor was tested in December, 1906, at the Government station at Frameries, in Belgium. By the courtesy of the Lahmeyer Co., who made the motor, the author communicated an account of the tests to the Institution of Mining Engineers (Trans. Vol. XXXVII., p. 489), in the following terms :—

"The tests were carried out on 24th December, 1906, under

the direction of Mr. V. Watteyne, Royal General Inspector of Mines; Mr. Stassart, Chief Inspector of Mines of the Belgian Corps des Mines; a branch of the Belgian Ministère de l'Industrie et du Travail; and Mr. Demuer, Chief Engineer of the Carbonnage du Bois du Luc, at which mines the motor was to be installed.

"The testing room in which the motor was installed was filled with fire-damp in the mixture of 6, 8, and at last 10 per cent. of fire-damp to 94, 92, and 90 per cent. of air, to ascertain whether the motor was able to fulfil the conditions of the contract.

"In the interior of the motor electric sparks were caused by means of a spark-gap connected to an induction coil of the Rhumkorff type, and in this way the gas inside the motor ignited.

"The fire did not at any one of the tests penetrate the covering of the motor, and the fumes were at all times sufficiently chilled so as not to ignite the surrounding gases.

"After this test had given good results, six pieces of gun-cotton were placed in the motor, and ignited by means of electric sparks. This explosion also did not penetrate the motor covering, and the series of tests were then closed; and it was allowed by the officials to install the motor in the mine in a place where there is constant danger of fire-damp explosions."

In the author's opinion a motor of such a type is far safer than an absolutely enclosed so-called gas-tight motor.

Explosion-proof motors are those in which an explosion outside cannot injure the motor and an explosion of gas inside the motor cannot injure the casing and so set fire to gas outside the motor. Many experiments both at home and abroad have been made in this direction with quite satisfactory results. Among the earliest were those conducted by Mr. W. E. Garforth, which are recorded in Appendix I. of the Report of the 1904 Departmental Committee. Cd. 1916.

In some quarters totally enclosed motors are objected to, as they are said to get very dirty. If a motor works under such conditions that the changes of temperature are very wide and the volume of air inside the motor casing is consider able, there must necessarily be considerable breathing, and if

such a motor is working in a dirty atmosphere dirt may get carried through into the motor. The only cure for this is to filter the air as far as possible or select a motor with a small temperature range. There are a large number of totally enclosed motors which have been working several years and with which no trouble whatever in this direction has been

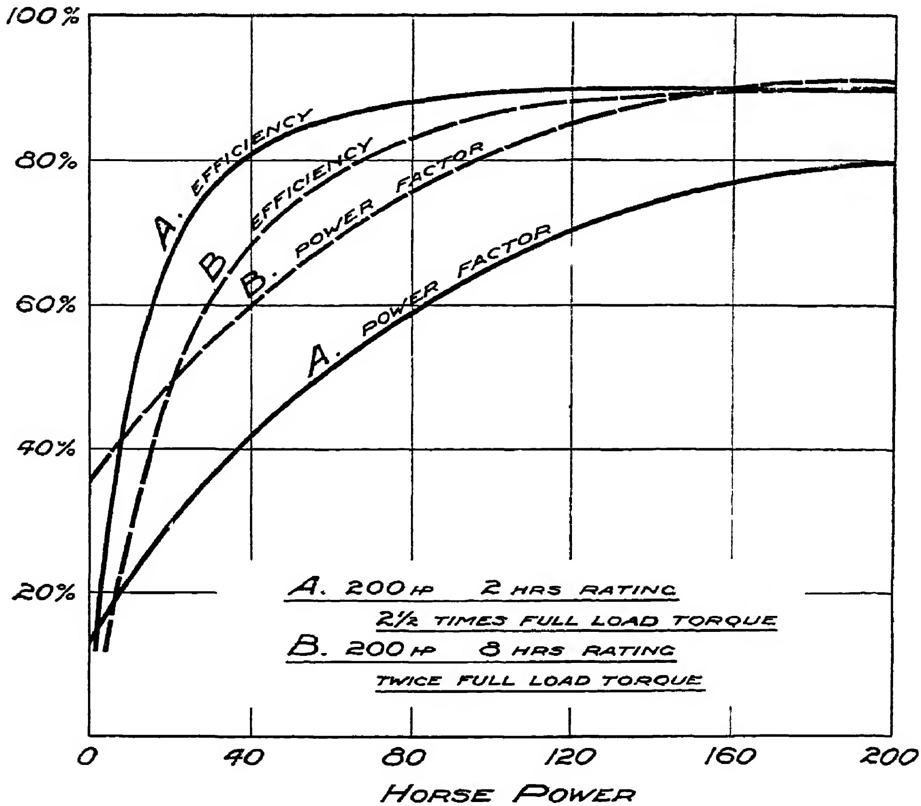


FIG. E1.—Curves of efficiency and power-factor for haulage motors with different torques.

experienced, and the motors when opened are now as clean as when they were started.

The output of a motor is limited by two important considerations :—

(*a*) torque, and
(*b*) heating.

(*a*) From the point of view of the torque the maximum

gradient is the deciding factor. The worst condition likely to obtain is when starting the load on a curve on the maximum gradient. This condition has to be covered, but can generally be rendered innocuous by care in handling the haulage; consequently, except under very special conditions, the maximum torque rating may be based on the conditions of full speed when running on the maximum gradient.

In a three-phase motor the maximum torque and the power-factor are intimately related, *i.e.*, the higher the breakdown torque of a motor the lower the power-factor: see Fig. E1.

The standard three-phase traction motor can develop a breakdown torque of twice the normal full load torque, and in this case a high power-factor is obtained. Hence, purely from the point of view of torque, the normal full load output of the motor may be determined from the expression

$$\frac{Q\,\text{max.} \times \omega}{2},$$

where Q = torque,
ω = angular velocity in radians, or $2\pi n$.

(*b*) As regards heating, this depends approximately upon the Root Mean Square torque of the motor. Not only is the process of arriving at an accurate figure for the Root Mean Square torque a laborious one, as the pull of the rope at the various positions along the road has to be calculated and the torque computed therefrom, but even if such a figure has been determined another difficulty arises in having to solve the problem of the intermittency of the motor, as the frequent starting and stopping and the periods of reduced speed-running will defy any determination of heating by the Root Mean Square torque rule.

Some authors have tried to express the intermittency of a motor in terms of the load-factor. This theory is applicable with a reasonable degree of accuracy to crane motors and other classes of motors, where the load conditions and cycle of operations are fairly constant. There is no reason why this rule should not be applied to haulages, providing the estimation of the load-factor is based on the worst conditions.

The load-factor "f" is determined from the expression

$$f = \frac{t_1}{t_1 + t_2},$$

where t_1 = running time

t_2 = resting time.

Most manufacturers, however, design their motors for three different ratings:—

(1) Continuous rating;
(2) Two-hour rating;
(3) One-hour rating.

It may be pointed out that a two-hour rating for motors such as are used for haulages practically corresponds to a 50 per cent. load-factor. Any load-factor below this would be considered as being covered by the one-hour rating.

Although, as before mentioned, it is useless to go to the refinement of calculating the Root Mean Square torque, it is easier to calculate the mean output of the motor based on the average gradient, and thus ascertain how far this mean output differs from the output obtained from the expression $\frac{Q \text{ max.} \times \omega}{2}$. In some extreme cases it may lead to an increase or decrease in the denominator of this expression. It is not economical to decrease the denominator much below 2, because, although a better power-factor is obtained, the machine becomes larger and the efficiency suffers.

Speed.—As regards the speed of motors, a slow-speed machine is preferable for haulage work on account of its greater capacity for heat storage. On the other hand, its cooling effect at full speed is less than that of the high-speed machine, but the ratio $\frac{\text{cooling at standstill}}{\text{cooling at full speed}}$ is more favourable.

An enclosed motor has a greater capacity for heat storage than an open type machine, but its cooling effect, which is very poor, again results in a high ratio for $\frac{\text{cooling at standstill.}}{\text{cooling at full speed.}}$

Haulage Calculations.—To fix these ideas it is helpful to consider a typical example of a main-and-tail haulage and an

endless-rope haulage designed for the same duty. Suppose the manager of the mine has supplied the particulars as to the quantity of mineral to be hauled per diem, the number of trips proposed to be run to handle that amount, which will depend, among other things, on the size of the wagons and the accommodation at the shaft bottom, the contour of the road, disclosing whether the gradients are with or against the load, whether the road is straight or has bad curves upon it, and the position of the curves as follows :—

I. Main-and-Tail.—Particulars of Road and Load.

CONTOUR OF ROAD.

Gauge of track		..	2 ft. $10\frac{1}{2}$ in.
Length	150 yards	..	6 in. per yard against load
,,	50 ,,	..	2 ,, ,, ,, ,,
,,	200 ,,	..	4 ,, ,, ,, ,,
,,	100 ,,	..	flat
,,	200 ,,	..	4 in. per yard against load
,,	100 ,,	..	6 ,, ,, ,, ,,
,,	700 ,,	..	3 ,, ,, ,, ,,
Total	1,500 ,,		

Maximum gradient	..	1 in 6
Average ..	..	1 in 10 approximately.

There are two 30-ft. curves in the track, which do not fall on a bad gradient.

LOAD.

Max. mineral to be hauled	..	360 tons per shift of 8 hours,
Load per single trip ..	..	20 tons,
Length of trip ..	..	1,500 yards.

Hence number of trips $\frac{360}{20} = 18$.

Average speed six miles an hour = 528 ft. per min., based on mean diam. of drum.

Time per single trip $\frac{1,500 \times 3}{528} = 8\frac{1}{2}$ minutes, or, say, 9 minutes, allowing for starting and stopping.

Allowing for changing at each end will bring the time taken per double journey, or round trip, to, say, 24 minutes ; this gives twenty round trips per shift, or 400 tons hauled, as a maximum, as compared with 360 tons as per requirements.

The maximum torque the motor will be called upon to develop can then be found.

The worst gradient is 1 in 6, and it is there that the maximum torque will be exerted. Speed at this gradient is 528 ft. per minute.

If

G = pull due to gravity effect of load,

F $\begin{cases} F_l = \text{pull due to friction of load, 0·03 found by test mentioned above,} \\ F_r = \text{pull due to friction of rope, 0·10, } i.e.\text{, is taken 1-10th of its weight.} \end{cases}$

Then total rope pull on a straight track

$$P = G + F.$$

On a curved track F is generally increased by 20—30 per cent. ; the total rope pull then becomes

$$P = G + 1{\cdot}3\,F.$$

The gravity effect of the rope is negligible, as the main rope balances the tail rope.

Applying this formula to the case in hand :—

Mineral per wagon	1·5 tons, about
Weight of wagon	0·5 ton
No. of wagons per trip	14, say
Weight of 14 loaded wagons	62,720 lbs.
Weight of rope 1 in. diam. (2 × 1,500 yds.)	14,650 lbs.

($3\frac{1}{8}$ in. circumf. at $9\frac{3}{4}$ lbs. per fathom.
Breaking load 33 tons, factor of safety 5—6).

Hence

$$G = \frac{62{,}720}{6} \qquad = 10{,}453 \text{ lbs.}$$

$$F\begin{cases} F_l = 62{,}720 \times 0{\cdot}03 = 1{,}882 \\ F_r = 14{,}650 \times 0{\cdot}10 = 1{,}465 \end{cases} = 3{,}347 \text{ lbs.}$$

$$0{\cdot}3\,F \text{ for curves } 3{,}347 \times 0{\cdot}3 = 1{,}000 \text{ lbs.}$$

$$P \qquad = 14{,}800 \text{ lbs.}$$

Consequently the motor must be capable of exerting a torque equivalent to a rope pull of 14,800 lbs , or, say, $6\frac{1}{2}$ tons.*

Allowing an efficiency of 80 per cent. for single reduction cast-steel, machine-moulded gearing increases the pull to 18,500 lbs.

$$\text{Output of motor } \frac{18{,}500 \times 528}{33{,}000} = 296 \text{ h.p.}$$

So that the maximum full-speed torque the motor will be called upon to exert is in torque equivalent to 296 h.p., or, say, 300 h.p.

As pointed out this is the top load for the motor, and it would be wrong to specify a motor designed to develop this torque continuously at normal full load, as it is only required for, say, one minute in twenty-four, or eighteen minutes in eight hours. According to the expression $\frac{Q \text{ max.} \times \omega}{2}$, the output of the motor would be $\frac{300}{2} = 150$ h.p

Now, consider what the average load is on the motor during the loaded and unloaded journeys. The mean gradient is 1 in 10, hence when hauling coal

G	=	6,272 lbs.
1·3 F	=	4,347 lbs.
Pull on rope, P,	=	10,619 lbs.
Allowing for gearing (80 per cent.)	=	13,300 lbs.

$$\text{Output of motor } \frac{13{,}300 \times 528}{33{,}000} = 213 \text{ h.p.}$$

When hauling empties in-bye the wagons will run back by gravity, and the work done by the motor is to overcome the friction of the rope.

* An easy formula for ascertaining the pull in the rope when the horse-power exerted by the haulage is known is

$$\frac{5{,}250 \times HP \times \eta}{r \times N}$$

Where η = the efficiency of the drum and gearing,
N = r p.m. of drum,
r = mean radius of drum (over the rope half wound on).

Hence

$$1{\cdot}3\ F = 1{\cdot}3 \times 14{,}650 \times 0{\cdot}10 = 1{,}905 \text{ lbs.}$$

Allowing for gearing (80 per cent) $= 2{,}380$ lbs.

$$\text{Output of motor} = \frac{2{,}380 \times 528}{33{,}000} = 38 \text{ h.p.}$$

The R.M S. h.p. corresponding to the complete double trip $=$ $\sqrt{\frac{213^2 + 38^2}{2}} = 153$ h.p., or, say, 150 h.p.

$$\text{Load-factor } \frac{18 \times 9 \times 2}{480} = 67\tfrac{1}{2} \text{ per cent.}$$

Consequently the specification will call for a motor with an output of 150 h.p., and a breakdown torque $= 2 \times$ normal, and with a temperature rise based on a load-factor of $67\frac{1}{2}$ per cent., which means practically a continuously-rated motor.

II. **Endless Rope Haulage.**—Contour of road as before, output as before, 360 tons per shift of eight hours to be handled on a double track, but in this case at a speed of, say, two miles an hour $= 176$ ft. per minute.

The load being distributed over the whole length of the road, it will be quite safe to base the output of the motor on the mean gradient 1 in 10.

$$\text{Wagons per hr.} = \frac{360}{8} = 45, \text{ or } \frac{60}{45} = 1\tfrac{1}{3} \text{ min per wagon.}$$

Average distance between wagons as the rope travels 176 ft. per minute $= 176 \times 1\frac{1}{3} = 235$ ft.

$$\text{Number of wagons} = \frac{\text{length of road}}{\text{distance between wagons}} = \frac{1{,}500 \times 3}{235}$$
$= 19.$

$$\text{Working load on rope} = \frac{19 \times 2}{10} = \frac{38}{10} \text{ tons} = 3{\cdot}8 \text{ tons, say,}$$

4 tons total, with shackles, &c.

Size of rope, $\frac{7}{8}$ in. dia.; weight ($7{\cdot}75$ lbs. per fathom) $=$ $\frac{7{\cdot}75 \times 1{,}500 \times 2}{2} = 11{,}600$ lbs.

(Breaking load 24 tons, factor of safety 5 to 6.)

Let $G_l =$ weight component of loaded wagons; $G_e =$ weight component of empty wagons.

$$G_l - G_e = \frac{(38 - 9{\cdot}5)\ 2{,}240}{10} \quad = \quad 6{,}380 \text{ lbs.}$$

Let F_l = pull due to friction of loaded wagons ; F_e = pull due to friction of empty wagons.

$$F = \left\{\begin{array}{l} F_l = 38 \times 2{,}240 \times {\cdot}03 = 2{,}550 \\ F_e = 9{\cdot}5 \times 2{,}240 \times {\cdot}03 = 640 \\ F_r = 11{,}600 \times 0{\cdot}10 = 1{,}160 \end{array}\right\} = \quad 4{,}350 \text{ lbs.}$$

0·3 F for curves .. .. .. 1,305 lbs.

Total rope pull P = 12,035 lbs.

Allowing for gearing, double reduction, steel machine moulded, 72 per cent. efficiency .. .. 16,750 lbs.

$$\text{Output of motor} = \frac{16{,}750 \times 176}{33{,}000} = \quad 89{\cdot}5 \text{ h.p.}$$

or to choose a standard size, say, 90 h p.

The maximum torque question would take care of itself, and as regards starting the load, this is also fully covered by the twice normal full-load torque, unless extra rapid acceleration is called for, which is unusual on an endless-rope haulage. Hence the specification would call for a motor for a normal continuous output of 90 b.h.p.

The above example shows that an endless rope haulage of this size would perform the same work as the 150 b.h.p. main-and-tail haulage; consequently the endless-rope type has a considerable advantage as regards first cost.

The mode of working of the main-and-tail and endless-rope haulages, as has been seen, is totally different. The first gives rise to a very fluctuating load, whereas on a system where the latter is installed the load is fairly even.

Let us consider which of the two is the more economical in actual working :—

Commercial Efficiency.—The *Main-and-Tail Motor* efficiency will be in the neighbourhood of, say, 85 per cent. during the time it is hauling a load and 75 per cent. during the time it is returning the empties.

Energy taken per shift :—

When hauling mineral $\dfrac{153 \times 746 \times 8{\cdot}5 \times 18 \times 100}{1{,}000 \times 60 \times 85} = 343$

,, ,, empties $\dfrac{38 \times 746 \times 8{\cdot}5 \times 18 \times 100}{1{,}000 \times 60 \times 75} = 96$

Total .. .. 439 B.T.U.

This is neglecting the extra power used at starting, as it is partly set-off by less current required when stopping.

The *Endless-Rope Motor* efficiency will be about 88 per cent.

Energy per shift $\dfrac{89{\cdot}5 \times 746 \times 8 \times 100}{1{,}000 \times 88} = 607$ B.T.U.

Capital Cost.

Main-and-tail haulage, erected complete, excluding rope	£2,500
Endless-rope haulage, ditto, ditto ..	£1,200

Running Cost.

Main-and-tail haulage, $\dfrac{439 \text{ B.T U.} \times 1d.}{360 \text{ tons per diem}} = 1{\cdot}22d.$ per ton.

15 per cent. interest and depreciation,

$\dfrac{2{,}500 \times 240 \times 15}{360 \times 300 \times 100} = 0{\cdot}83d.$ per ton.

Total cost per ton of coal hauled, exclusive of labour $= 2\ 05d$ per ton

Endless-rope haulage, $\dfrac{607 \text{ B.T.U.} \times 1d.}{360 \text{ tons per diem}} = 1{\cdot}68d.$ per ton.

15 per cent. interest and depreciation,

$\dfrac{1{,}200 \times 2{,}400 \times 15}{360 \times 300 \times 100} = {\cdot}40d.$ per ton.

Total cost per ton of coal hauled, exclusive of labour $= 2{\cdot}08d.$ per ton.

It will be noted that the price per unit of electricity has been taken at 1*d*. It is only fair to say that this comparison is slightly unfavourable to the endless-rope haulage, as with the tariffs usually quoted, an endless-rope haulage, owing to its steadier demand, would be able to obtain electricity at a cheaper rate than a main and tail.

known, and from the following formula connecting mass M with velocity V, pull P and time t:—

$$M \times V = P \times t$$

$$P = \frac{M \times V}{t}.$$

For the present case assume that on normal work time $t = 20$ seconds for starting up, then useful work $= 200 \times 20 = 4{,}000$ h.p. seconds.

Now, as is well known, when speeding up a three-phase motor of the slip-ring type, the loss in the resistance equals the useful work, hence the losses will also equal 4,000 h p. seconds. This expressed in heat units =

$$\frac{4{,}000 \times 550}{778} = 2{,}840 \text{ B T.U., or 717 calories.}$$

This heat has to be dissipated, say, by oil-immersed, water-cooled resistances. Supposing a case without water cooling, then the following conditions obtain :—

Pit temperature	63° F
Max. oil temperature	156° F
Specific heat of oil	0·5
,, gravity	0 9
Oil in circulation . ..	123 gallons say 1,110 lbs

To raise the oil to 156° F. requires $1{,}110 \times \cdot 5 \times 93 = 51{,}600$ B.T.U.; which is equivalent to $\frac{51{,}600}{2{,}840} = 18$, say, startings up.

This, however, does not allow for working at reduced speed, which often occurs for considerable periods, not only when starting, but also during the trip; consequently, unless a much larger quantity of oil is provided, recourse must be had to artificial cooling.

The final temperature of the oil of 156° F. quoted above is quite permissible for underground working, provided it is not exceeded.

In the haulages at Ferndale the oil is drawn off from the top of the resistance cases and forced through cooling elements by means of a small pump which is driven from the drum shaft, as previously mentioned.

The temperature rise of two similar 200 h.p. equipments

operating under different conditions was investigated some time ago and is shown in Table E1.

The upper part of the Table shows the work done by each haulage set during the two shifts making a twenty-four hour day's work. The lower part shows the temperature attained by the motors and oil-immersed resistances respectively. In the case of the motors the maximum reading is given, while the temperature of the oil is given at four stated times during the twenty-four hours.

In No. 4 set the oil temperature varied very little during the day, as the amount of work done at reduced speed was very small and the roads were in good condition.

In No. 1 set the oil temperature varied during the day shift, between 7 a.m. and 4.30 p.m., from 140° to 167° F. This could have been greatly diminished if less running with the resistance in the rotor circuit had been possible, which at the time was not practicable owing to the bad condition of the road not permitting full speed to be run with safety. The higher temperature on this resistance during the night was owing to the large amount of shunting in connection with repair work, including the transport of timber and materials in-bye.

TABLE E1.

PARTICULARS OF TRIPS RUN DURING AN ORDINARY DAY'S WORKING (TWENTY-FOUR HOURS) OF TWO 200 H.P. 2,200 VOLT HAULAGE SETS.

Haulage No.	Shift	Particulars of Trips.			No of Wagons	
		No	Time in Minutes Full.	Time in Minutes Empty.	Coal.	Rubbish
4 ..	day night	22 5	5 5	2 2	233 tons 54 tons	—
Total	..	27	135	54	287 tons	—
1 ..	day night	21 4	7½ 7½	1¾ 1¾	192 4	3 45
Total	..	25	157	37	196	48

Day shift from 7 a.m. till 4.30 p m.
Night ,, ,, 7 p.m. ,, 4.30 a.m.

TEMPERATURE ATTAINED DUE TO ABOVE WORKING.

Part of Motor Equipment	Temperature		Remarks
	No 4	No 1.	
Motor after day's work—			
Rotor winding ..	72° F.	73° F.	Temperature of pit steady at 63° F.
,, core ..	77° F.	79° F.	
Stator winding ..	77° F.	82° F.	
,, core ..	81° F	88° F.	
Slip rings . ..	75° F.	86° F	
Resistance at 7 p.m.	122° F	122° F	
Resistance at 7 a.m	119° F.	113° F.	
Resistance at 4.30 p.m	140° F	154° F	
Resistance at 7 p.m.	120° F.	127° F	

Anxiety has been felt in some quarters as to the advisability of taking oil into a coal pit or using oil-immersed transformers near the top of a down-cast shaft. Oil may be used to put a fire out, but, on the other hand, if the oil is heated it will readily ignite and then prove dangerous It is therefore advisable to control the temperature of large bodies of oil. Contact thermometers may be arranged to ring bells and raise an alarm should the temperature rise to a predetermined point, but such thermometers are delicate and readily deranged

The author persuaded the Pearson Fire Alarm Co. to take the matter up, with the result that they have adapted their alarm for immersion in oil, and have turned out a strong and serviceable instrument.

In connection with transformer or switch oil having a flash-point of 300°—350°.F. such alarms may be used which are calibrated from 100°—200° F. The exact point at which the contact is made can be readily adjusted, and the instrument provides a sure and ready check on the temperature of the oil with an ample factor of safety.

Sand Filling for Resistances.—For many years past Messrs. Siemens have used sand for filling iron tubes containing wire coil resistances, and have turned out strong and quite satisfactory resistances on these lines. The circulation that is obtained in oil-filled resistances is of course absent, but there is no reason why this method should not be used on a larger

scale. It must necessarily be more bulky, as the units must be relatively smaller to permit adequate radiation, as the conductivity of sand is somewhat low, but the resultant resistances would be much stronger, and more capable of withstanding rough work, than an oil-filled type.

Locomotives.—The question of haulage by electric locomotives is at the present time interesting in view of the legislation on the question. Under the 1904 Special Rules electric haulage by locomotives on the trolley wire system was only prohibited in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applied, and in such a place, if storage battery locomotives were used, the Rules applying to motors in such places were deemed to apply to the boxes containing the cells. Those Rules have now been superseded by the new code, in which No. 19*a* states : "Haulage by electric locomotives on the overhead trolley wire system is prohibited in any part of a coal mine." No. 19*b* states : "Haulage by electric locomotives on the overhead trolley wire system may be used in mines other than coal mines, and haulage by storage battery locomotives may be used in any mine with the consent in writing first obtained of the Secretary of State in all cases and subject to such conditions affecting safety as may be prescribed by him."

Until the 1st July, 1912, "mine," as already mentioned, included every shaft in the course of being sunk, and every level and inclined plane in the course of being driven, and all the shafts, levels, planes, works, tramways, and sidings, both below ground and above ground, in and adjacent to and belonging to the mine. The new Act, which came into operation on the first day of July, 1912, in clause 122 describes "mine" in exactly similar terms, to which, however, the following words are added : "but does not include any part of such premises on which any manufacturing process is carried on other than a process ancillary to the getting, dressing, or preparation for sale of minerals." The question is therefore likely to arise in the early future, when is a mine not a mine for the purpose of an electric locomotive ?

On the Continent a large number of electric locomotives on

the overhead trolley system are used, and have been found to be extremely convenient. The author has been taken about three miles in-bye behind such a locomotive, and when sitting in the bottom of a tub he had occasionally to duck his head to prevent contact with the trolley wire, in spite of which he was informed that accidents due to the use of the system were exceedingly rare. It, however, is not such an arrangement as could be generally recommended.

A useful description of a 220 volt continuous current overhead system at the Shamrock I. and II. Collieries, Herne, Westphalia, appears in Vol. XXXIX., Trans. Inst. Min. Eng. In these pits the wires are fixed at a minimum height of 6 ft. above the rails and carried on insulators fixed about 20 ft. apart. Each locomotive is provided with two compound wound motors each having a normal 11·8 and maximum 17·7 h.p., so that each locomotive has a normal rating of, say, 23·5 and maximum 35·5 h.p. The motors are wound for 220 volts and run at 500 r.p.m., driving the wheels through 5·33 to 1 gearing. The weight of the locomotive is 11,000 lbs. and the tractive force normally 570 lbs., with a maximum of 1,940 lbs. The wheel base is 52 in., and the diameter of the wheels 26¾ in. With the normal 500 r.p.m., the locomotives run at eight miles per hour. Six locomotives are in constant use and two others are held in reserve. The plant deals with 1,920 wagons of coal in seven-and-a-half hours, which is equivalent to an output of 2,116 tons per diem.

The length of haulage road at present equipped is about four miles and longest single run about one-and-a-half miles. The gauge of the rails is 24 in. and the weight of the rails which have been found rather light, is 30 lbs. per yard, so they are being replaced by a heavier section weighing 36 lbs. per yard. Steel sleepers are used which are placed about one yard apart, and to which the rails are attached by clips and bolts. The maximum radius of the curves is 32¼ ft. The average gradient of the road is about 1 in 450, and is in favour of the load. This small gradient is favourable to the locomotives, and is said in some measure to account for their success; in certain cases, however, the full load is drawn up a gradient of as much as 1 in 80.

The costs of the plant are given for a month representing twenty-six working days of sixteen hours each, during which 15,725 B.T.U. were used and which are charged at 0·36*d*. per unit. Interest on capital at 4 per cent. and renewal of plant at 4 per cent. is included in the costs.

—	Ton-kilometres	Ton-miles	Cost per English Ton-mile. Pence
Coal, stone, &c ..	88,579 84	55,008	1 38
Coal	72,464 64	45,000	1 69

—	Metric Tons.	Cost per Ton	Cost per English Ton
Total coal output ..	54,010 65	1 39*d*.	1 12*d*
Total tons carried ..	68,308·25	1·10*d*	1·42*d*

It is stated that the appointment of a competent person, whose sole duty it was to superintend and regulate the traffic of the locomotives, was, to a great extent, the means of raising the ton-miles worked by each locomotive from about 111 to 151 per shift.

In England the use of electric locomotives for mining work is not so common. So far as the author is aware, there are none under ground and not many on the surface. One of the most complete equipments is that of the Harton Colliery Co., who, according to the description in the *Iron and Coal Trades Review*, 2nd December, 1910, were operating six locomotives. The complete equipment was supplied by Messrs. Siemens Brothers' Dynamo Works; three of the locomotives are of 100 h.p. nominal rating, two of 200 h.p.—these being four-motor machines—and the sixth is of 260 h.p. This latter locomotive, which has a weight of 25·85 tons, is equipped with two motors each of 130 h.p. on one-hour rating. Each motor is suspended in the usual way and coupled to the driving axle by single reduction gearing with a ratio of 5½ to 1. The tractive effort, therefore, due to the whole locomotive is four tons. The

locomotive has a 9 ft. 10¼ in. wheel base, and an overall length of 20 ft. 3 in. The contact with the 550-volt overhead wire is made by Messrs. Siemens' bow collector, which is mounted on the roof of the driver's compartment in the centre of the locomotive.

Current for this locomotive equipment is supplied from a special sub-station containing one 200 k.w. motor generator and one 350 k.w. Siemens' Rotary Converter, which is capable of giving an overload of 25 per cent. for six hours and 50 per cent. for half an hour. It has been found in practice that the single rotary converter has sufficient capacity for the whole of the work performed by the six locomotives. Figures taken over a week show the energy consumption per gross ton-mile and per ton-mile of coal :—

Gross Ton-miles	Coal Transported	Ton-miles of Coal.
54,682	18,200 tons	17,089

Average consumption per ton-mile, gross	= 74 watt hours
Average consumption per ton-mile of coal	= 236 ,, ,,
Average distance a ton of coal has been carried	= 0·93 miles

The consumption includes the energy required for hauling the empties back to the pit The operation of these locomotives has been so satisfactory that for an extension to the colliery a further eight miles of overhead line have been equipped and two locomotives weighing in all about 40 tons and provided with four 70 h.p. 550-volt motors have been ordered.

Accumulator Locomotives.—Little has been done in this direction at present, but it is not at all unlikely that a good deal more may be heard of it in the future, as the system would afford much greater security and simplicity for yards than obtains under either overhead wire or third rail construction. In Messrs. Sulzer's works at Winterthur, Accumulator Locomotives are used for handling railway trucks and also the small

trucks which transport parts of machines from one shop to another in the works The wear and tear is very small, and the system has given absolute satisfaction. In some cases the locomotives are built as such and haul the load behind them in the usual way. In other cases they are built as flat trucks with the batteries and motors underneath, and upon the flat tops of the trucks, which are quite free from obstruction of any kind, loads of any dimensions can be placed The driver stands on a step at the back of the truck

The following approximate working costs for mine railways including interest, capital, wages, maintenance, cost of current and material, are given by the A E. G. Co. of Berlin, who have supplied about 1,000 locomotives for mines :—

Working costs for continuous current locomotives with overhead contact line ..	0 5 to 0·65*d.* per ton-mile.
Working costs for accumulator locomotives ..	1 0 to 1·15*d.* ,, ,, ,,

CHAPTER VI

WINDING ENGINES

The work of a Winding Engine is to raise the loads of mineral, &c , to the shaft top or "bank," as it is called. The capacity of the winder is primarily determined by the tons of mineral to be raised and the depth of the shaft.

At collieries the wagons of coal are run into the cage by the "hitcher" at the shaft bottom, and are pushed out of it by the "banksman" at the shaft top. A cage may have several decks, as many as six being employed; the simplest form has only one deck, upon which one wagon, or two in tandem, may be loaded. Where ore is handled the place of the cage is taken by a skip, into which the ore is shot at the bottom of the shaft and from which it is discharged into a hopper or wagons at the top.

Cage Loads.—In winding a certain quantity of mineral a fixed amount of work has to be done irrespective of the rate at which the mineral is wound. The work done is generally expressed as shaft horse-power seconds.

$$\text{Shaft horse-power} = \frac{W \times S}{T \times 550},$$

where W is the weight of the mineral per wind,
S ,, depth of the shaft, and
T ,, time in seconds per wind.

This expression is a basis of comparison for winders.

The mineral can be raised by :—

(*a*) Frequent winds with a small amount of mineral per wind; or

(*b*) Few winds with a heavy load per wind.

A compromise has to be found between these two conditions. It will be seen that the advantage of winding a large quantity

of mineral at one time is that less time will be taken in banking.

Mr. Livingstone (*Electrician*, Mining Issue, 10th June, 1908, p. 32) has given a schedule stating the time used for banking, which is given in Table F1.

TABLE F1.

No. of Levels at which Trucks are Changed.	Time for Changing, in Seconds					
	One Truck per Deck			Two Trucks per Deck.		
	Single-deck Cage	Two-deck Cage	Three-deck Cage	Single-deck Cage	Two-deck Cage	Three-deck Cage
1	7	16	27	10	22	36
2	–	8	18	—	11	24
3	–	—	9	—	—	12

In order to make the subject more graphic take a concrete example and assume a winder for a duty of 240 tons per hour from a depth of 800 yards. Suppose that at the colliery there are trucks available which carry 1½ tons each ; the winder will have to raise 1½ tons or multiples of 1½ tons useful load. The coal must then be wound as per the following Table F2.

TABLE F2.

Tons of Coal per Wind.	No. of Winds per Hour	Time per Wind.	Time per Wind, less Banking	Average Speed in Feet per Second
3	80	45	35	69
4½	54	67	58	41·5
6	40	90	79	31
9	27	135	123	19·5

Note.—A load of 1½ tons has not been included, because this is ruled out by the abnormal high speed ; 7½ tons cage loading is impracticable on account of unequal loading per deck, unless five decks were used.

Ropes.—Round ropes are generally preferred in this country for winding. Some of the earliest engines had round ropes wound on reels in place of wide drums, and were provided with counter-balances in the shape of heavy chains attached to a

rope wound on to a drum of small diameter , isolated instances may still be found in mines in the North of England and also in South Wales. In the Belgian coalfield flat ropes, which consist of a number of round aloe ropes stitched together side by side, are often used. Round ropes are of uniform diameter and weight throughout their length. Flat ropes can be made taper by decreasing the width or number of ropes stitched together, while the thickness of the rope remains the same. This gives an excellent opportunity for decreasing the out-of-balance load.

Locked coil rope is at present extensively used, as it has the following advantages :—

(1) It gives the greatest strength for the smallest diameter and weight.
(2) Having a smooth surface the wear by friction is minimised.
(3) It does not spin.
(4) It is freer from internal corrosion than others.

As previously mentioned, the harder the steel wire the greater the breaking stress, but the greater the liability to crack when bent ; hence larger diameters of drums and pulleys are necessary and a compromise has to be found Experience has shown that for winding ropes a breaking stress of about 110 tons per square inch on the wires is satisfactory. For deep shafts this value may have to be increased to 120—130 tons per square inch.

Size of Rope.—In winding the rope is the all-important factor. Old practice was to choose a rope with a static factor of safety of 8 to 10. In this factor of safety stress due to acceleration was ignored, consequently the 8 to 10 factor gave a false impression of security, and in practice actually dwindled down to 6, especially in steam winders when the starting torque is very irregular.

At the Dusseldorf International Congress of 1910 a margin of safety of 6 was advocated by the Prussian Commission for winding minerals, with the stipulation that when winding men the cage should not be loaded beyond half the weight carried when winding minerals. They claimed that this comparatively

low factor of safety of 6 is perfectly justified in view of the stringent test the ropes have to undergo before being accepted

In practice the capping or method of attaching the rope to

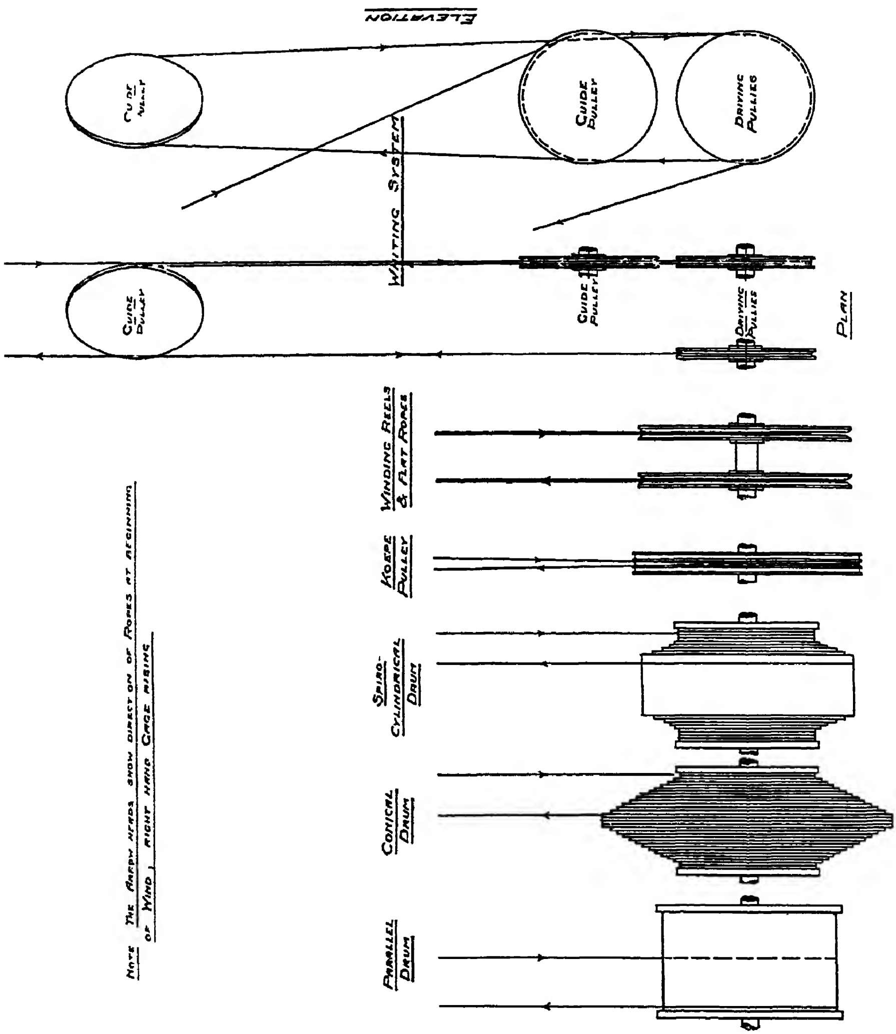


FIG 51 —Types of drums for six methods of winding.

the cage is the point that causes most anxiety. The average life of a rope may be taken as three-and-a-half years, but re-capping is necessary at intervals of not more than six months to comply with the requirements of section 40 (5) of the 1911 Act.

Types of Drums in Use.—Fig. F1 shows the different types of drums generally employed.

(1) *The parallel or plain cylindrical* drum is certainly the most popular. As it is not considered good practice to coil a winding rope in two layers on a drum, if the depth of wind is great the drum must be of large diameter and wide. In a wide drum the distance between the pit head-gear pulleys has to be considered, otherwise there is considerable friction on the side of the rope. A unique method of getting over this difficulty is found in the Morgan engine at Dolcoath, in Cornwall. The engines are supported on girders, which travel on rails at right angles to the pull of the rope a distance equal to the thickness of the rope for every revolution of the drum, which is 10 ft. in diameter and 21 ft. in length, and will accommodate 3,000 ft. of rope (*The Engineer*, 16th March, 1900)

(2) *Conical or simple spiral* drums in which the spiral increases at an even rate have been employed, and are excellent from the point of view of balancing, but are costly to construct, very heavy in proportion to their strength, and are difficult to handle.

(3) The *spiro-cylindrical* is a combination of the two first types. It has been used in France, but is best known in South Wales, where it is identified with the name of Mr. E. W. Hann, who first employed it in Aberaman. Several other instances may be found in South Wales, and an excellent modern example is fully described in Mr. Hugh Bramwell's paper on the "Equipment of the Maritime Pit" (Proc. S. Wales Inst. of Eng., Vol. XXVI., p. 140). In going into the design Mr. Bramwell found that it would be better to depart from the usual practice of making the spiral rise at an even rate, and developed a design in which the work diagram is materially improved owing to the spiral coiling on the drum at a varying rate up the cone, thus increasing the diameter at first rapidly and afterwards more slowly. A short cylindrical drum face is provided at each end of the spiral in this type of drum.

In both this and the previous type some difficulty may arise in decking the cages, as the two cages travel different distances for a given movement of the drum. Another difficulty which has been found in operation is that if for any reason the engine

has stopped before the load is wound quite up to the bank the engine may be unable to finish the wind, as it is not strong enough to start the load with the rope on the full diameter of the drum. It is therefore necessary to let the load run back a certain distance down the shaft until a less out-of-balance condition obtains and the engine is able to control the load.

(4) The *Koepe pulley* is the invention of a German mining engineer of that name, and consists of a friction pulley of large diameter, with a grooved face in place of the wide drum. The groove is sometimes packed with rope, but more generally with wood or leather, in order to increase the friction. The rope from the top of one cage passes over the pit head gear round the Koepe pulley, over the other pit head gear to the second cage. A balance rope goes from the under side of the second cage to the bottom of the shaft and up to the under side of the first cage to which it is attached. This system is very popular in Germany, but has been very little used in this country, perhaps the only instance at work for any length of time being the Sneyd Colliery (Trans. Inst. Min. Eng., Vol. XVIII., p. 450, and Vol. XXX., p 282). If one asks why it is not used in this country the reason generally given is that if the rope breaks both cages must necessarily fall. The author has frequently inquired, and has personally sought, for instances of failure, but has been unable to find one, so that the danger appears to be rather more sentimental than real. Another objection is the slipping of the rope, which may occur to a slight extent, especially when the loading of the cages is very unequal. The effect of this slip is cumulative, and, as the winding engine attendant stops the engine when a mark on the periphery of the pulley or drum coincides with a pointer, the slip renders it difficult for him to stop the engine and bank the cage properly, so that this calls for constant adjustment of the depth indicator.

A new rope stretches, and the excess of length has to be corrected by taking out links from the chains which have been inserted above the cages for that purpose. When sufficient chain has been taken out, the rope can be re-capped, the chain being re-inserted; but probably the most real objection to the system is the difficulty of re-capping sufficiently often when the rope has not stretched enough to allow it.

The weight of a Koepe pulley is considerably less than that of a corresponding drum, and the small width occupied by the pulley makes a very efficient and neat arrangement for electric winding. The record of life of ropes used on Koepe pulleys is very good, due to the large diameter of the pulley and the slower rate of acceleration and retardation, which is generally employed to avoid slipping of the rope.

It is interesting to note that by section 40 (4) of the 1911 Act "keps for supporting the cage when at rest are to be provided at the surface level where mineral is usually unloaded, but the provision of keps shall not apply to a system of winding by means of a single rope where the ropes are held by the friction of the rope on a winding sheave," so that although the system is little used at present, the Act does not debar it. The point, of course, is that keps would take the weight of the cage off the rope which would therefore slip on the pulley.

(5) *Winding reels* were employed on some of the earliest winding engines; instances may still be found in the pits in South Wales and in the North. This system is still commonly employed in the Belgian and North of France coalfields, where tapered flat hemp ropes are generally employed. An excellent balance may be obtained when a flat rope is employed coiled upon itself on a narrow drum while a similar rope is being uncoiled from a similar drum.

(6) The *Whiting* system is a development of the Koepe system, inasmuch as it is an attempt to increase the surface of the pulley and friction of the rope upon it. The rope, instead of being taken once round the driving pulley, is taken several times over a pair of pulleys, and a tension pulley is provided by means of which the length of the rope in the shaft may be adjusted. With this system a balance rope is necessary, as in the case of the Koepe pulley. It has been employed to a small extent in deep mines in South Africa, but is not likely to become popular.

Motor to Drum Connection.—Some of the early Cornish engines were geared to the winding drums but in this country, except in the case of small and relatively unimportant machines,

it is usual to connect the motor direct to the drum shaft. This calls for a slow speed and heavy equipment.

Improvement in gearing is being taken advantage of, especially in South Africa, where many geared winders are now running, although they are small as compared with the main winders employed in British or German collieries. For instance, the Cinderella Deep Mine Co. are using two winders for their main shaft, which will be 3,000 ft. deep. Each winder has a Westinghouse 180 h.p. three-phase 50-cycle slip-ring induction motor, capable of carrying 450 h p. for short periods, coupled through double reduction gearing to an 8-ft. drum. The gearing is by the Power Plant Co. of double-helical steel for the first motion, and of machine-moulded cast iron for the second motion.

The load is 3,000 lbs. of ore in a 2,500 lbs skip. The rope is 3 in. in circumference and the winding speed 1,000 ft per minute. The control is by liquid resistance switches, in which the electrodes are fixed and the height of the liquid is varied.

The drums or pulleys are generally keyed on to the shaft and the motor reversed as necessary. There are exceptions, however, to this arrangement, as in the case of a large winding engine lately started at the Consolidated Copper Mines near Kelvin, Arizona. In this case the motor runs continuously, always in one direction. The two-drum hoist is driven by ropes, and the drums are controlled by friction clutches. The motor is an alternating current machine rated at 300 h.p., 430 r.p.m , and drives a drum shaft by thirty-two 1-in. ropes. The load handled is 21 tons gross, which is raised from a depth of 500 ft. at a speed of 300 ft. per minute.

Position of Motor.—In England the motor or engine is always on solid masonry foundations on the ground level. An interesting variation occurs in several cases on the Continent, where the motor is erected at the top of the pit head gear.

The first instance was probably the Ligny les Aire equipment, supplied by the Lahmeyer Co. some nine or ten years ago, where it was necessary to hoist 105 tons of coal per hour from a depth of 1,300 ft. at a speed of 26 ft. per second. The winding gear was erected directly over the shaft in a tower standing in

a base 30 ft. square ; the tower has tapered sides and a height up to the winder floor of 69 ft. The winding machine consists

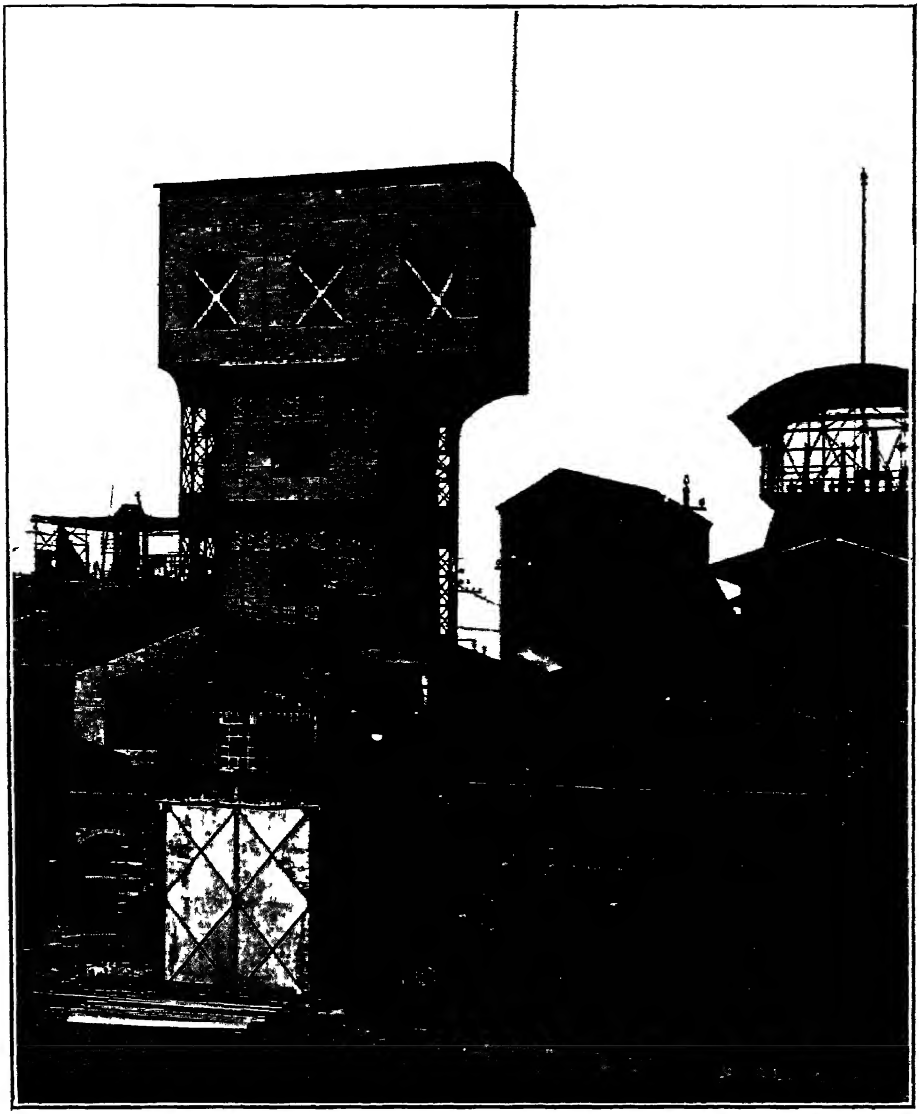


Fig. F2.—Winder-house on pit-head gear.

of two 250 h.p. motors directly connected to two drums on the same shaft ; the diameter of the drums is 13 ft. 2 in. The

power at starting is about 600 h.p , and when the full speed of 38 r.p m. is attained the power falls to 300 h p.

At the Deutschland Colliery, Upper Silesia, a winder supplied by the A. E. G Co. of Berlin was erected on a pit head gear which takes the unusual form of a parallel steel frame without any external stays (Fig. F2). The motor, by the A. E. G. Co. is 630 h.p. at 63·7 r.p.m., and is directly coupled to a Koepe pulley 14 ft. 9 in diameter. The unusual arrangement was due to the lack of ground space, but the equipment was found to be so economical and satisfactory that it was repeated, and now the two shafts at this colliery are equipped with similar winding machines.

Mechanics of the Winding Problem.—The simplest form of winder consists of a cylindrical drum driven by a steam engine or other motor. On the drum two ropes are coiled in opposite directions, so that as one is wound up the other is unwound, and when half unwound they balance each other. These ropes are led from the drum over a pair of sheaves in the headgear, and are each attached to a cage ; when one cage is at the bank the other is at the shaft bottom, and they reverse their relative positions at each wind.

Consider first the static moments on the drum due to the pull on the rope during one wind. It must be mentioned here that in order to arrive at the static moment the shaft friction is expressed in lbs. weight, and, as it always opposes motion, it is added to the weight on the ascending rope. Hence, for a cylindrical drum the resultant static moment at any shaft position will be

$$(W_1 + F - W_2)\,r,$$

where
W_1 = ascending weight,
F = shaft friction,
W_2 = descending weight,
r = drum radius.

It is clear that the smaller the resultant static moment, the smaller will be the required starting torque. Fig. F3 shows how the static moment is affected by the weight of the rope. The vertical scale represents the resultant static moment ; the

horizontal scale represents the depth of the shaft In each case the same load and friction have been assumed.

Case 1 represents the static moment for the cage in any

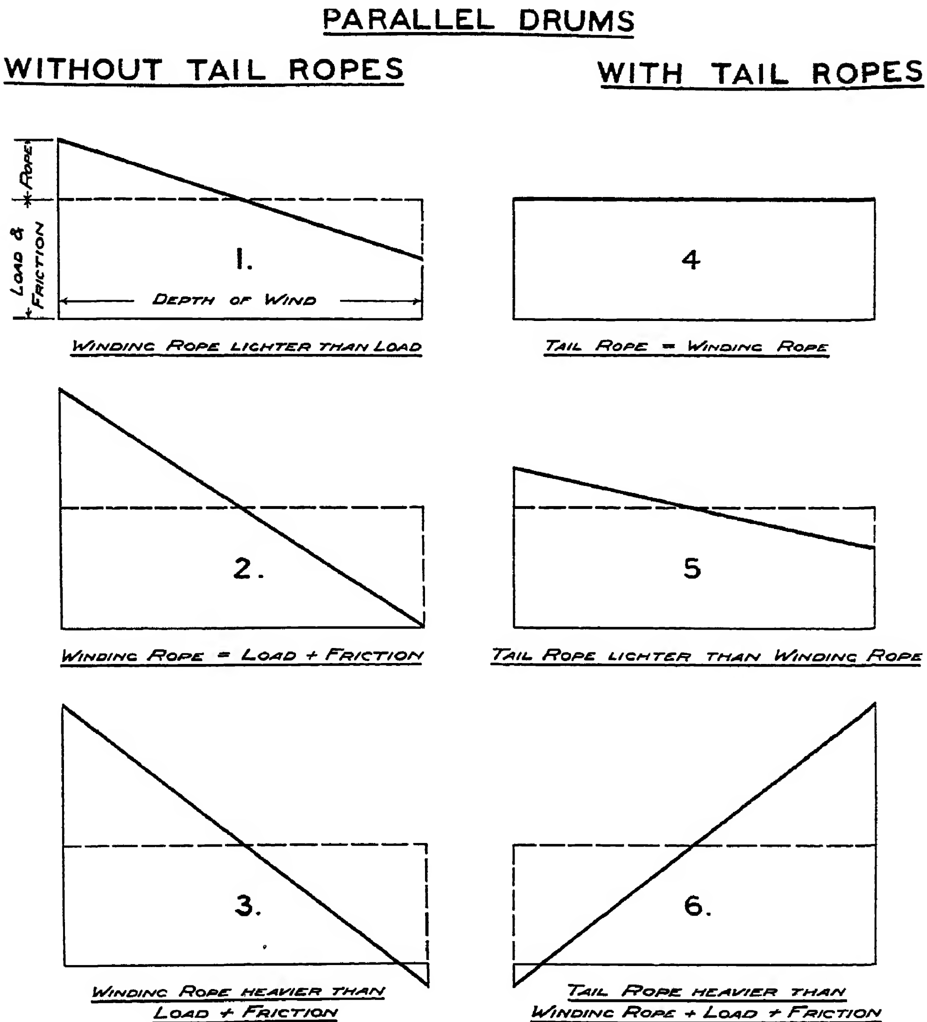


FIG. F3.—Static moments of winders with parallel drums.

position in the shaft when the useful load exceeds the weight of the winding rope, as in a shaft of moderate depth.

Case 2 represents conditions where the winding rope is equal to the weight of the useful load.

Case 3 represents conditions where the weight of the winding rope exceeds the useful load and overbalances the load at the end of the wind as in a deep shaft.

It was soon recognised that in order to minimise the starting torque it would be necessary to equalise as much as possible the static moments in the ropes Many devices were adopted, of which two are extensively used. The best known is the balance rope, the other method is the conical drum, and modifications of that type.

The balance rope is generally made of the same weight per unit length as the winding rope, in which case the static moment diagram will correspond to a rectangle, *Case* 4.

By decreasing the weight of the balance rope, conditions as shown in *Case* 5 are obtained, and by increasing it *Case* 6 is obtained. It might be desirable sometimes to do this, although, as will be seen later, the reduction in the starting torque obtained by increasing the weight of the rope may, to a large extent, be discounted by the fact that increasing the weight of the rope increases the masses in the system, and this is responsible for an increased starting torque, also for extra stress on the rope during the braking period, so that the remedy might be worse than the disease.

The *Balance Rope* has not been so much used as it might have been ; the reason probably is not directly due to the rope, but to the engine. The irregular turning of steam winding engines causes considerable swing in the rope between the drum and the pit-head sheaves, and is often very perceptible when riding in the cage. The surges between the drum and sheaves are small compared with what can occur between the cage and the bottom of the shaft, so the antipathy which mining engineers have had to balance ropes on steam-driven winders is easily justified. Modern engines are a great improvement in this respect, and electric motors give such regular turning that surges are not experienced. Where motor-driven and steam-driven winders are running side by side the difference is very marked, one rope runs like a rod, while the other is surging and whipping all the time of the wind.

When using the conical or spiro-cylindrical drum no balance rope is used, and the main ropes are arranged in such a way

that the rope fixed to the cage at the bank is wound on a much larger radius than the rope attached to the loaded cage which is at the bottom of the shaft. In this way the static moments are equalised. In some cases even the resultant

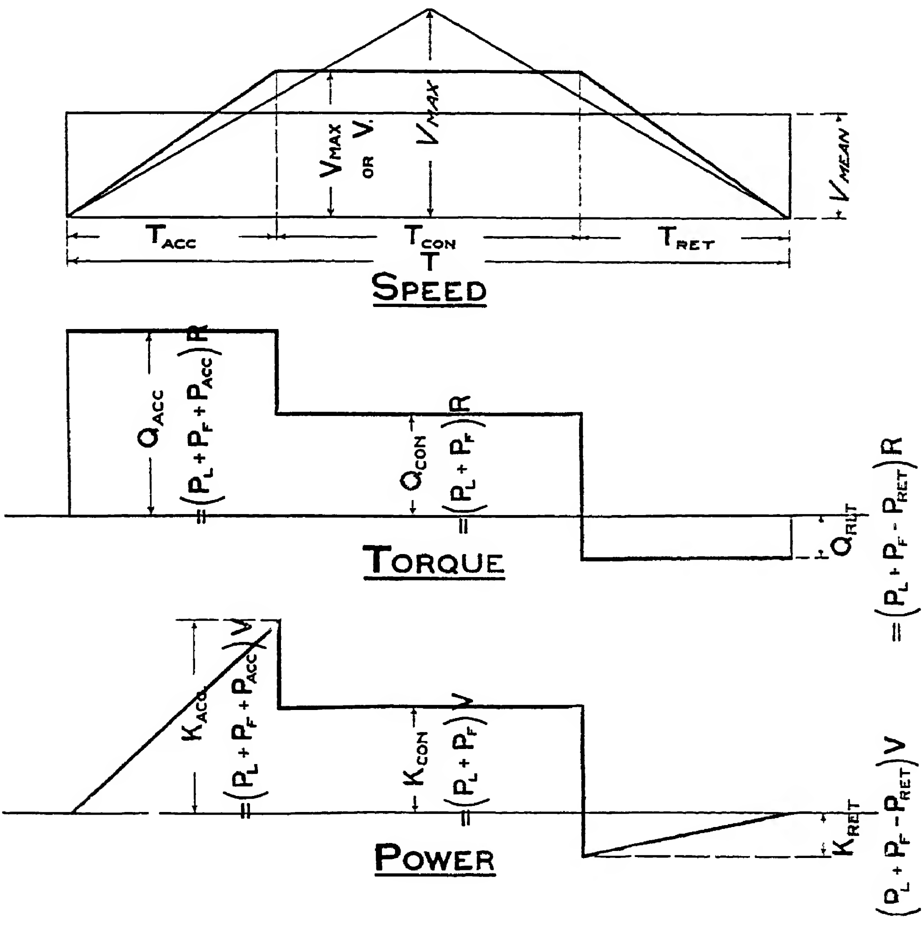


FIG F4 —Speed, torque, and power diagrams for a winder with parallel drum.

static moment is in favour of the empty cage (as in *Case* 6, *ante*), so that the winder will start by itself.

Speed Diagram.—The *Speed Diagram* of a winder takes the form of a trapezoid (Fig. F4), of which the base line T represents the time to complete one wind, and the height V the full speed.

The area of this diagram, therefore, represents the depth of the shaft. It is clear that this diagram can assume any shape between a rectangle and a triangle, these two figures forming the extreme conditions. In the case of a rectangular speed diagram (which in practice is impossible) the acceleration and retardation are instantaneous, and the maximum speed V will also be the average speed. At the other extreme, viz., a triangular diagram, the average speed will be half the maximum speed; and there will be no full speed period, *i.e.*, as soon as acceleration finishes retardation begins.

From this it can be deduced that in practice the V_{mean} speed must always be more than half the V_{max}.

Referring to Fig. F4,

S = area of speed diagram = depth of shaft,
T_{acc} = time in seconds for acceleration,
T_{ret} = ,, ,, ,, ,, retardation,
T_{con} = ,, ,, ,, ,, full speed run.

As the practical speed diagram has the shape of a trapezoid the following formulæ are obtained :—

$$S = V_{max} \times \frac{T + T_{con}}{2}, \text{ or } S = V_{max} \times \left(T - \frac{T_{acc} + T_{ret}}{2}\right),$$

$$\text{hence } T_{acc} + T_{ret} = 2\,T - \frac{2\,S}{V_{max}}, \text{ or } V_{max} = \frac{2\,S}{T + T_{con}}.$$

The V_{max} must be chosen as near V_{mean} as possible, in order to have as long a period for the full speed run as is compatible with the permissible acceleration and retardation rates.

Consequently, if V_{max} is stipulated the other factors can be determined.

It must be borne in mind that in setting out the speed diagram practical considerations limit the permissible maximum speed. Speeds of 70 ft. per second are becoming fairly common, although not very much exceeded at present. The highest speed which has come to the author's notice is 92 ft. per second, but this is exceptional.

Before the speed diagram can be definitely settled the acceleration and retardation rates must be determined. These

may vary greatly in different instances, although a value of 4 5 ft. per second per second for acceleration is very high and hardly ever exceeded. It naturally depends upon the depth of shaft and cage loading, although it must not be forgotten that a limit is imposed by the motor, inasmuch as the torque during the accelerating period ought not to be more than about twice to two-and-a-half times the full speed torque. As regards retardation this should, so far as possible, be arranged that no external braking is necessary.

The **Torque Diagram** is easily derived from the speed diagram (Fig. F4).

The total pull P in the rope is made up of three components—

Pl = Pull due to the out-of-balance load.

Pf = Friction, which always acts in opposition to the motion, and which amounts to 18—20 per cent. of the useful load.

P_{ac} = Force necessary for accelerating the masses, which is the product of the total masses in motion by the rate of acceleration, or $M \times A_{ac}$.

P_{rt} = Force necessary for retarding the masses, which is the product of the total masses in motion by the rate of retardation, or $M \times A_{rt}$

With a cylindrical drum or a Koepe pulley all the moving parts can be reduced to the drum diameter, by applying the following formula to each rotating member :—

$$\frac{W \times \kappa^2}{g \times r^2},$$

where

W = weight

κ = radius of gyration of rotating member ;

r = radius of drum ;

g = gravity.

Particulars as to weights and radius of gyration of the sheaves, drums, motors and other rotating parts, if any, must be obtained from the manufacturers. In connection with the equivalent masses in motion, Mr. Stjernberg points out in his paper that " for cylindrical drums the ratio between the static load Q (load and friction) and the mass M varies somewhat,

but between comparatively narrow limits. With a distance between the pit-head pulleys of 5 to 6 ft., $\frac{M}{Q}$ lies between 1·1 and 1·3 (in the metric system). The larger value corresponds to pits of about 500 to 600 yards depth with a useful load of about 3 tons; for shallower pits or larger loads a smaller value can be taken. If instead of cylindrical drums Koepe pulleys are used, this value may be as low as 0 8."

Let

Q_{acc} = torque during acceleration,
Q_{con} = ,, ,, full speed run,
Q_{ret} = ,, ,, retardation.
A_{acc} = acceleration in feet per second per second,
A_{ret} = retardation ,, ,, ,, ,, ,, ,,
R = radius of drum,
M = equivalent mass of system.

Then

$$Q_{acc} = (Pl + Pf + P_{acc})\,R,$$
$$Q_{con} = (Pl + Pf)\,R,$$
$$Q_{ret} = (Pl + Pf - P_{ret})\,R.$$

Power Diagram.—The power K is obtained by multiplying the values of the pull on the rope with the corresponding speeds V; hence

$$K_{acc} = (Pl + Pf + P_{acc})\,V,$$
$$K_{con} = (Pl + Pf)\,V,$$
$$K_{ret} = (Pl + Pf - P_{ret})\,V.$$

From these values we can establish the Power Diagram (Fig. F4).

To obtain the mean power during the winding period it is only necessary to calculate the area of the power diagram and divide by the base or the time taken.

Size of Motor.—The size of motor is determined by the Root Mean Square torque, Q_{rms}, calculated over the running period, as this torque determines the heating of the motor; hence

$$\text{Motor output} = \sqrt{\frac{Q_{acc}{}^2 t_{acc} + Q_{con}{}^2 t_{con} + Q_{ret}{}^2 t_{ret}}{T}} \times \text{angular velocity.}$$

A motor calculated on this basis will give the temperature rise obtained when the same machine is running continuously at the R.M.S. torque.

Example.—Having considered the various points that arise in calculating a winder problem, it will help to make them a little more fixed in the mind if they are applied to a definite case.

To recapitulate, the consecutive steps in the calculation of a winder are as follows :—

(*a*) For a given cage loading and a given quantity of coal to be raised per hour the number of trips and the time per trip can be fixed, as also the average speed.

(*b*) The size of rope to be used can be fixed by calculating the stress, this being equal to the sum of the suspended weights plus the friction, plus the accelerating force.[1]

(*c*) From the rope diameter is determined the diameter of the drum and sheaves

(*d*) The inertia of all the moving masses can now be calculated as acting at the radius of the drum.

(*e*) The inertia being known, acceleration and retardation rates can be established.

(*f*) Having found the acceleration and retardation, the speed diagram can be determined.

(*g*) From the speed diagram the torque and the power diagrams are determined

(*h*) From the torque diagram the horse-power of the motor is determined.

In Table F3, four cases of winding 240 tons per hour from 800 yards depth are shown. The cage loadings are for multiples of $1\frac{1}{2}$ tons, as mentioned earlier (p. 136). As will be noticed with a 3-ton cage loading, the maximum speed becomes impracticable, so this case has not been pursued.

In estimating the stress in the rope the weight of the cage and the bridles has been taken as one-and-a-quarter times the weight of coal, and the wagons as half the weight of the coal. These are values which obtain in practice, although they may vary widely in different districts.

[1] For a preliminary estimate the accelerating force may be taken as equal to the sum of the useful load, plus 20 per cent. for friction.

For estimating the total masses in motion acting at the drum radius the weight and radius of gyration of the various parts must be known. When working out an actual case these are readily obtainable, but when working out an imaginary case we must either rely on empirical formulæ or proceed in the manner indicated by Mr. Stjernberg (as mentioned previously), whose values appear quite near enough for ordinary purposes.

In the present example the motor ratings for the different cage loadings work out—

1,675 h.p. for the $4\frac{1}{2}$ tons,
1,106 h.p. for the 6 tons,
940 h.p. for the 9 tons,

so that purely from the point of view of the motor the 9-ton equipment will be the cheapest. As a rule, in practice there are important conditions which limit the choice of cage loading. When using $1\frac{1}{2}$-ton wagons, the $4\frac{1}{2}$-ton and the 9-ton cage loadings call for three-deck cages, whereas the 6-ton calls for a double-deck cage. Whether or no the pit bottom lends itself to a cage of this kind is a point to be decided by the colliery manager.

It will be noticed that the energy per ton of coal is the same in each case; this is because the same value has been taken for shaft efficiency. In practice the shaft efficiency would vary for slow and for quick winding.

Electrical Problem.—The load on the winder being of such an extremely fluctuating character, it presents a very interesting problem for an electrical engineer.

On some winders now at work the load varies from 0 to 3,000 h.p. in the space of a few seconds; naturally an enormous increment of load of this description is very difficult to handle, and cannot be coped with by a Supply Company with a limited output, but in localities such as South Africa, where a Power Company is equipped on a large scale and is prepared to take risks, a large number of three-phase winders are now at work taking their supply direct from the network, with or without motor generators, but in either case without any auxiliary fly-wheel or equalising apparatus.

TABLE F3.—Winders.

240 tons per hour from 800 yards depth.

Cage loading, per wind		3 tons single deck	4½ tons three decks	6 tons double deck	9 tons three decks	Remarks.
No. of winds per hour		80	54	40	27	
Total time per wind	secs	45	67	90	135	
Banking time	,,	10	9	11	12	
Running time	,,	35	58	79	123	
Average speed per wind, V_{mean}, ft. per sec		68.6	41.5	30.4	19.5	
Stress in rope, P:—						
Weight of coal	tons	—	4.5	6	9	
,, ,, cage and bridles	,,	—	5.625	7.5	11.5	Taken as 1¼ × coal weight
,, ,, wagons	,,	—	2.25	3	4.5	Taken as ½ × coal weight
,, ,, rope	,,	—	6.8	9	13.5	
,, ,, friction	,,	—	0.9	1.2	1.8	Taken as 20% of coal weight
Total static pull	,,	—	20.175	26.7	40.3	
Accelerating force	,,	—	4.9	7.2	10.8	Taken as coal weight − friction
Total pull on rope	,,	—	25.075	33.9	51.1	
Rope diameter	inch	—	$1\frac{13}{32}$	[illegible]	[illegible]	
Weight per fathom	lbs.	—	35	40	54	
Breaking stress	tons	—	155	205	227	
Factor of safety	.	—	6.2	6	6	
Drum diameter	ft.	—	16	18	22	Taken as 100—120 rope diameters
Reducing all masses to the drum radius M:— Drum and shaft, Ropes complete, with tail rope, Motor armature, Pit head pulleys, Cages, Trams, Coal	Total absolute Units, or Poundals at drum radius	—	3,640	4,200	6,000	Using Steinberg's factor 1 metric = 0.30 English
Speed diagram:—						
T_{con}, in secs		—	20	62	110	
V_{max}, in feet per sec		—	60	34	20.6	
A_{ret}, ,, ,, per sec		—	3.31	3.84	4.03	
T_{ret}, in secs		—	18.1	8.85	5.1	
T_{acc}, ,,		—	17.9	8.15	7.2	
A_{acc}, in feet per sec per sec		—	3.35	4.17	2.61	
Torque diagram:—						
Q_{acc}, in ton-feet		—	86.7	135	196	
Q_{con}, ,, ,,		—	43.2	64.8	119	
Q_{ret}, ,, ,,		—	—	—	—	
Q_{rms}, ,, ,,		—	54.9	71.9	123	
Motor ratings		—	1,675	1,106	940	
Power diagram:—						
K_{acc}, in h.p.		—	2,650	2,080	1,495	
K_{con}, ,,		—	1,320	1,000	907	
K_{ret}, ,,		—	—	—	—	
Average power at drum shaft	h.p.	—	910	887	861	
Energy in k.w. hrs. at drum shaft per ton of coal		—	2.4	2.4	2.4	

It is also interesting to note that the Maritime winder, referred to on p. 139, *ante*, is now being operated off the mains of the South Wales Power Co. without the equaliser with which it was originally provided, and the Harton winder is similarly worked from the mains of the Newcastle-on-Tyne Electric Supply Co.

CHAPTER VII

TYPES OF ELECTRIC WINDERS

Types of Winders.—The electrical equipment of the winder must be selected with due consideration of the supply from which the energy is to be drawn.

Two main classes of winding plants have been developed :—

(A) Winders where the motor is directly worked off the supply main ;

(B) Winders where the motor works in conjunction with equalising apparatus for levelling the peak and diminishing the maximum demand from the supply main.

These two classes can be subdivided into the following types :—

Class A (1). Three-phase motor coupled direct to the winder and supplied direct from the Power Station, which is the most commonly used type in this class (Fig. 61).

In this type there is the minimum number of links in the chain between the generator and the winder, but this simplicity is obtained coupled with important disadvantages.

The great fluctuations which occur in the energy called for render it practically impossible, except in a case where the maximum demand for the winder is only a small proportion of the demand on the Power Station, otherwise the variation of the pressure on the system renders the supply objectionable, if not useless, for other purposes. This is probably one of the chief reasons why it is being abandoned at the classic example of this system at Preussen II., near Dortmund.

There is a large loss during the acceleration period, as the useful work plus the rheostatic loss is constant ; hence the efficiency is low, only about 45 per cent.

As the speed during the retardation period is not above synchronism, no power can be returned to the supply system.

On the other hand, the efficiency during the period of full speed is high, possibly 90 per cent., and as the capital outlay is relatively small, owing to the absence of equalising plant, the upkeep is small except on the resistance switch, the work on which is severe.

On a very large power scheme the fluctuations caused by the operation of many winding engines ought to cancel out, and in the aggregate cause no more inconvenience than is caused by a service of many tramcars, given, of course, that the plant was designed with suitable units. The Victoria Falls Power Co are taking this line in connection with the supply to the mines on the Rand. In his paper (Journal Inst. Elec. Eng , Vol. XLVI , p. 207) Mr. Heather states the Power Co do not object, so he is putting down winders of this type for the mines on which he is engaged, and he deals very fully with the possibilities of this type, in which, under the special circumstances of the case, he is a firm believer. Mr. Heather uses double reading polarised ammeters in the motor circuit to tell whether the driver ought to increase or decrease the resistance in the rotor circuit in order to alter the torque, and claims thereby to have brought the simplicity of control of an induction motor exactly level with that of a continuous current motor.

That there is a very definite advantage in current consumption in operating without the fly-wheel equaliser is shown in two fortnightly records given by Mr. Bramwell for the Maritime winder (Proc. S. Wales Inst. Eng., Vol. XXVII., p. 299).

TABLE G1.

—	With Fly-wheel.	Without Fly-wheel
Fortnight ending	26/6/09	1/10/10
No. of winds of all sorts	5,260	5,370
B.T.U. used	29.800	17,800
Tons of coal raised	5,986	6,043
B.T.U per ton of coal	4 26	2·94
„ „ wind	5·66	3 31

A very real objection to this type is that in the event of the supply failing the winder is stopped perhaps in the middle of a wind, and if men have to be got out of the pit this is a serious

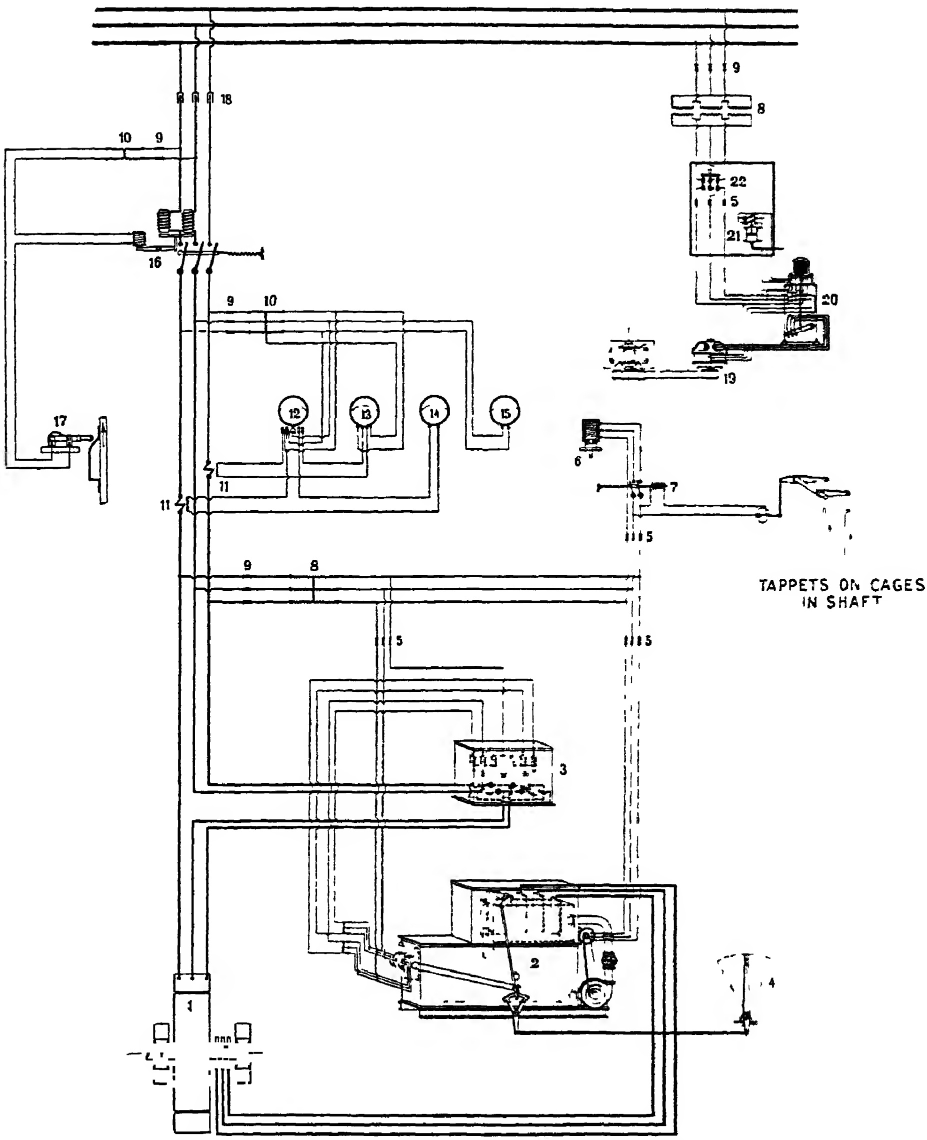


FIG. G1.—Diagram of connections for three-phase winder.

1 Winder motor
2 [illegible]
3 [illegible]
4 [illegible]
5 L. T. fuses
6 Brake magnet
7 Switch operated by overwinding device in shaft
8 Transformer
9 H. T. fuses
10. Potential transformer.
11 Current transformer
12 Meter
13 Wattmeter
14 Ammeter
15 Voltmeter
16 Oil switch, with maximum and no-load release
17. [illegible] apparatus
18. [illegible]
19 Compressor motor.
20 Automatic starter for compressor motor
21. Automatic switch.
22 Quick-break switch.

matter. In sinking a shaft at the Cinderella Deep Consolidated G.M. Co., power is taken from the high tension lines of the Victoria Falls Power Co. in a region where thunderstorms are frequent. To enable the men to be wound out of danger a small fly-wheel set is employed, which is run only when blasting is about to take place; the arrangement has been found very useful and effective.

The classic examples of this type of winder are the Preussen II., near Dortmund, which was started in 1902, and the Grand Hornu, near Mons, which was started in 1904.

At Preussen II., a three-phase, 2,000-volt, 50-cycle motor giving 1,380 h p. maximum is coupled direct to a Koepe pulley 19 ft. 6 in. diameter. The maximum hoisting speed is 52 ft. 6 in. per minute, with a nett load of 1 ton. About 100 tons per hour are wound from a depth of 750 yards.

At Grand Hornu a three-phase motor working at 1,250 volts, $23\frac{1}{2}$ cycles, and giving 940 h p. maximum is directly coupled to the drum shaft, upon which there are two reels for flat ropes. The minimum diameter of the reels is 4 ft. 2 in., the maximum diameter 25 ft. 9 in. The rope is of aloe fibre and flat in section, tapering down from 12 in. $\times$ 2 in. to $8\frac{1}{4}$ in. $\times$ $1\frac{3}{16}$ in. A similar machine was started in the following year.

Fig. 61 shows diagrammatically the scheme of connections as employed by the A.E.G Co., the reference numbers on which make the diagram self-explanatory. The starting and regulating resistance, No. 2, is of the liquid type, in which the plates are fixed and the resistance is varied by altering the level of the liquid. The upper part of the tanks is the resistance proper; the lower part acts as a reservoir and cooling tank. The valve which controls the level of the liquid is shown connected to the quadrant worked by the driver's lever, which also works the main switch, No. 3, in the stator by means of a relay, the switch controlling which is fixed on the end of the resistance tank.

Both these plants were operated from private Power Stations, but the fluctuation of pressure caused was so great that a large amount of extra plant had to be kept running to cope with it, and, as previously mentioned, the Preussen II. set is now being abandoned.

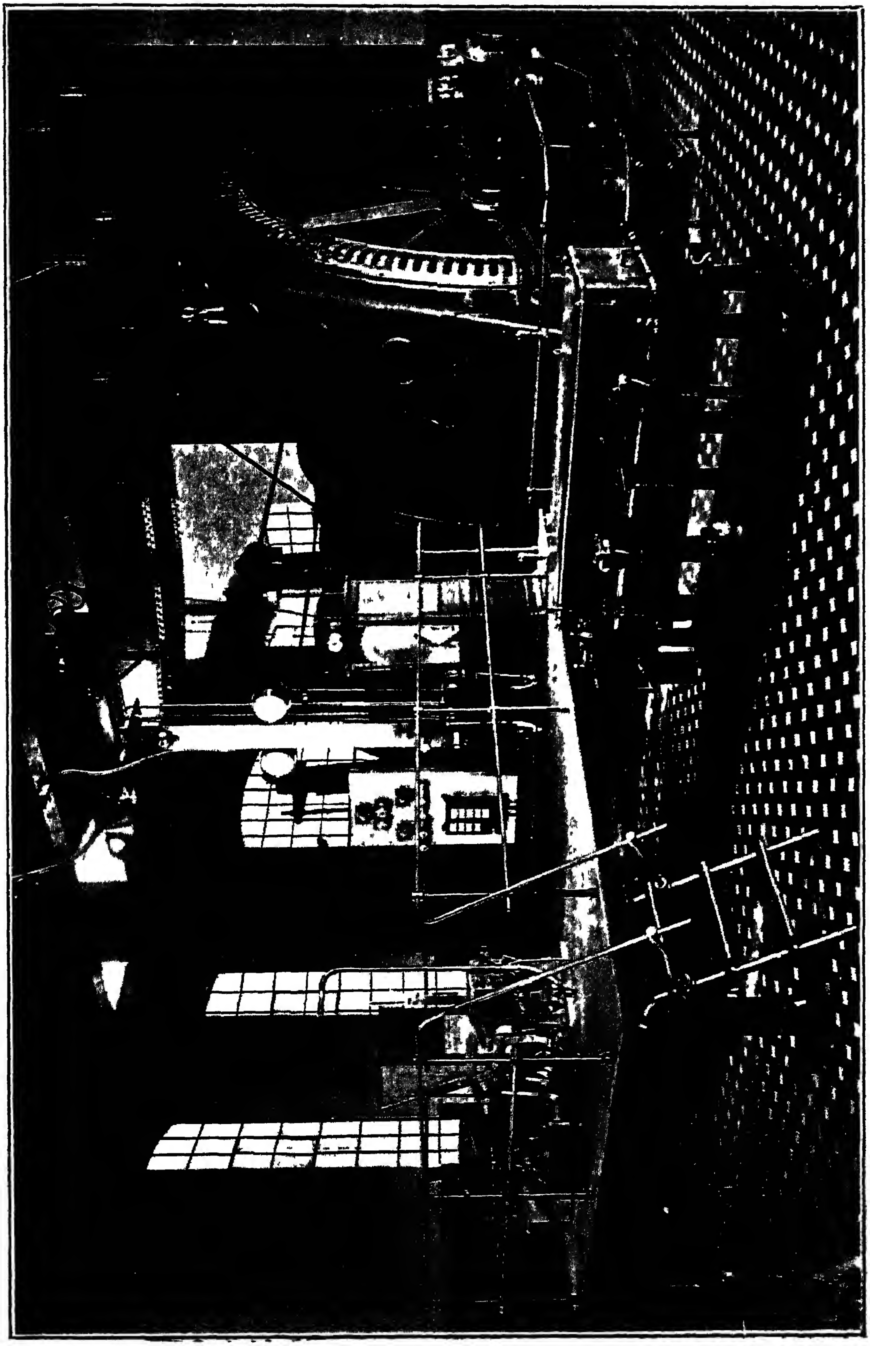


FIG. 62 Siemens' winder at Hanton Colliery.

An excellent modern example of this system is to be found in the Siemens equipment at the Harton Colliery, which was

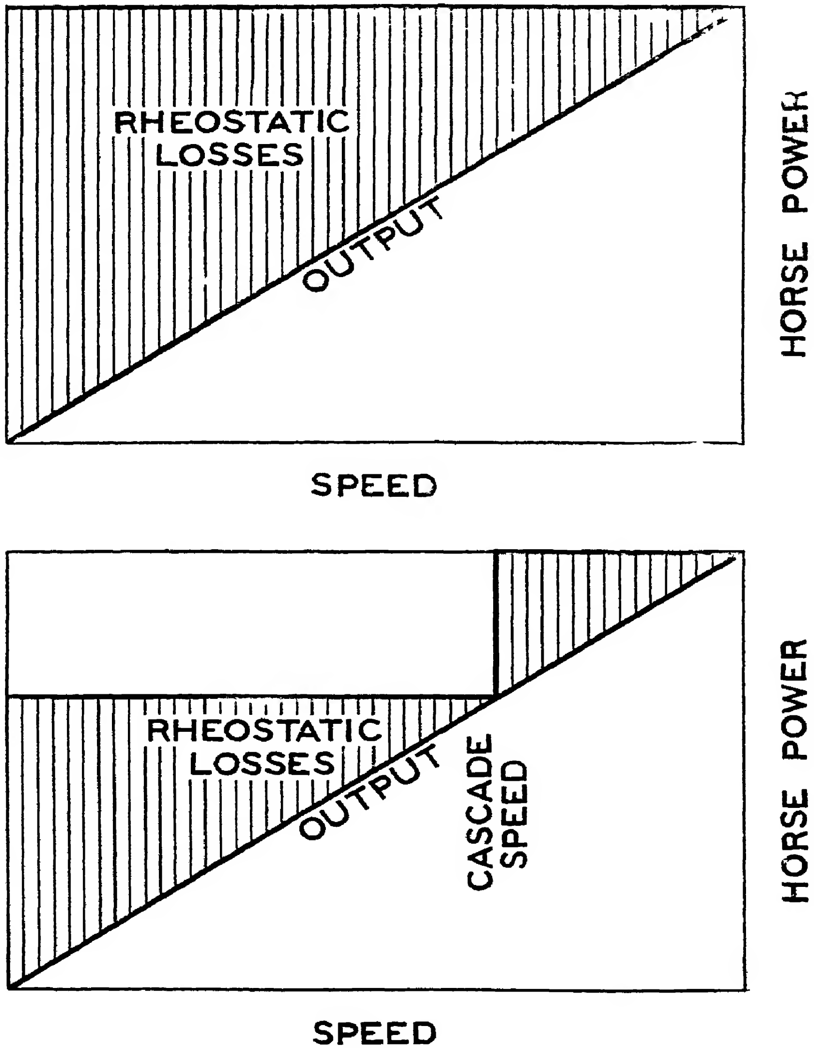


FIG. G3 —Starting losses with ordinary slip-ring and Sandycroft-Hunt cascade motors.

started about two years ago (Fig. G2). In this case three-phase energy is supplied from the mains of the Newcastle District Electric Supply Co. at 6,000 volts, 40 cycles. The

winding motor is of 800 h.p. normal rating, but works up to 1,700 h.p. at starting. It winds from a depth of 1,300 ft. at a normal speed of 51 r.p.m., which is equal to 36 ft. per second. The control is effected by means of a liquid resistance in the rotor circuit, the slowing down being partly done by the post brakes. The blades of the resistance are moved by a motor into or out of the water as required.

Class A (2). Winder driven direct from the supply by a Sandycroft-Hunt patent variable speed cascade motor.

The chief feature of this motor is that two efficient speeds are obtainable, full speed and two-thirds speed, with the possibility of any intermediate speed by rheostatic control in the rotor. Regulation below two-thirds speed is effected by means of rheostatic control in the stator winding: in this case the rheostatic losses will correspond to the lower speed and not to the full speed, as is the case in the ordinary three-phase motor with rheostatic control in the rotor

Fig. 63 shows the losses incurred when starting an ordinary three-phase motor and a Sandycroft-Hunt motor respectively. The area of each figure equals the input to the motor; the vertical scale represents torque and the horizontal scale speed. The shaded areas represent energy wasted in the resistances. The point is shown at which cascade speed obtains.

The motor is started on the cascade connections, thereby obtaining a high torque with low current value; this not only reduces the starting losses, but also considerably reduces the peak, and, in many cases, makes the proposition practicable where the ordinary three-phase motor drive would be unsuitable.

Another advantage is that regenerative braking is available during the retardation period up to cascade speed, when further braking can be obtained by the admission of counter-current or by mechanical brakes as desired. The control of the motor is very simple, and a uniform torque is obtained, even at creeping speeds for shaft inspection, &c.

Where a shaft is in the initial stage, this arrangement presents the further advantage that during the development period the motor can wind at cascade speed.

This application of the Hunt motor is new, and as yet no

practical example is at work, although shortly a hoist for an inclined shaft of the Singareni Mine in India will be in operation. This matter is further explained on p. 204.

Class A (3). Winder driven by two single-phase commutator motors on one shaft.

Messrs. Brown, Boveri & Co. have adapted the single-phase Deri motor to run from a three-phase circuit by connecting two such motors across the three phases. In this way the set consists of two stators, and two rotors each with a commutator, coupled on one shaft. The great advantage of this system is that no starting or regulating apparatus of any kind is necessary, as all starting, regulating, and reversing is effected by shifting the brushes on the commutators. Further, the motor can be directly coupled to a high tension supply without the intermediary of a transformer, and as the rotor is not electrically connected to the stator it can be wound for low tension. The motor can be used for electric braking and is regenerative at all speeds, and also possesses the advantage of a large starting torque. The disadvantage is that owing to the introduction of commutators the sparking may cause trouble, although this difficulty has been overcome for motors of less than 750 h.p. output.

An instance of this system is found at the Czeladz Mines in Poland, where a 280 h.p. machine is winding from a depth of about 700 ft.

Class A (4). Winder driven by a continuous current separately excited motor, the continuous current being obtained from a motor generator, the motor of which is driven by three-phase energy and the generator controls the motor on the Ward-Leonard system.

An instance of this is to be found at the Koenigshutte Colliery in Upper Silesia, where the equipment was supplied by the A. E. G. Co. of Berlin. The motor generator is supplied at 6,000 volts, and it is rated at from 300 k.w. normal to 630 k.w. maximum, with a speed varying from 585 to 630 r.p.m. The winding motor is rated at 360 h.p., at 42·5 r.p.m., and is supplied with current at 500 volts from the motor generator, with Ward-Leonard control. Eighty-four winds are made per hour, 34 seconds being allowed per wind, which leaves about 9

seconds for banking. The depth of the shaft is 617 ft., and the ordinary nett load wound is two tons.

NOTE ON WARD-LEONARD CONTROL.—This consists of a

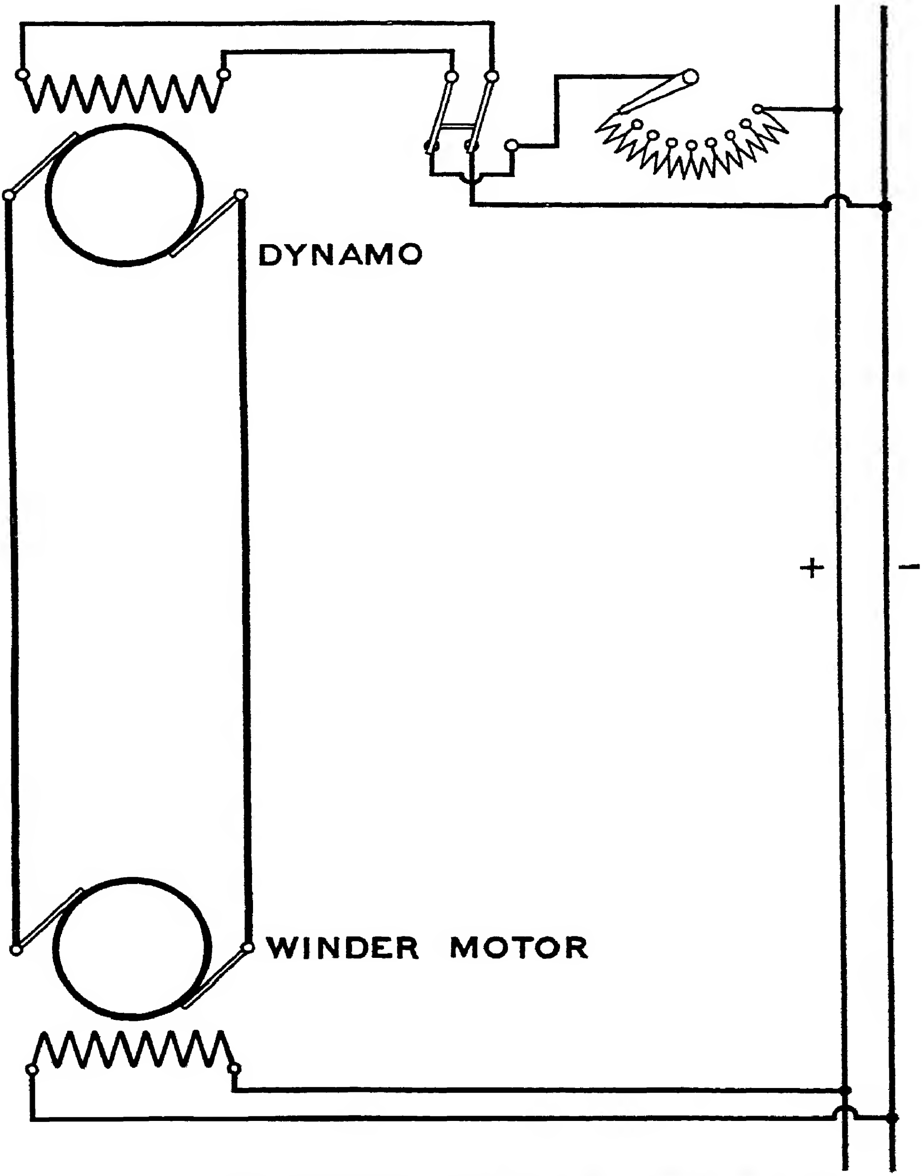


FIG. G4.—Ward-Leonard control as applied to electric winders.

separately excited or shunt wound dynamo, the brushes of which are connected direct to the armature of the separately excited winder motor. The dynamo field is reversible, and varied from zero to full voltage in either direction by the insertion of a resistance. Consequently the pressure, and hence the current, of the winder motor, whose field is kept steady, is also varied from zero to maximum value (Fig. 64).

Class A (5). Series Parallel System.—Winder driven by two series motors controlled on the series parallel principle. The operation of this system is so well known that it does not need description. An installation of this kind is at work at the New Modderfontein Mines, South Africa; particulars of this installation are given in Table 64, p. 187.

Class A (6) Winder driven by continuous-current separately excited motor, with Ward-Leonard control, the current being supplied by a steam turbine set, which drives both a continuous-current generator and a three-phase generator for supplying the other plant at the mine.

A very interesting example of this type, supplied by Messrs. Brown, Boveri & Co, is to be found at the Heinitz Mine in Upper Silesia. The advantage of this system over the Ilgner is that there are less links in the chain, and the fly-wheel mo or generator is not necessary, as the overload on the winder is taken care of by a by-pass valve on the steam turbine. So far as economy in steam goes there is little to choose between this and an ordinary steam winder, as the boiler capacity must be sufficient to meet the maximum demand when accelerating the load, whereas with the Ilgner system the boiler only has to supply the average load. The Heinitz plant is not yet working to full capacity. The plant is designed for a

Depth of shaft	2,526 ft.
Useful load in tons	7
Speed, ft. per second	32·8
Diameter of Koepe pulley ..	26 25 ft.
Cage	4 decks, with 3 wagons per deck.

The turbine has a maximum rating of 1,700 k.w. and is fitted with an automatic overload valve, which throttles the steam

during normal load, but at full load opens, so that the throttling is removed, and, further, can admit live steam to the second stage of the turbine. The operation of the winder affects the speed of the turbine some 2 per cent, but this has not been found detrimental. The continuous-current generator has a normal rating of 450 k.w. with an overload capacity of about three times this amount. It is wound for 500 volts, and is provided with a Deri winding, which gives sparkless commutation at all loads. The three-phase generator which supplies other plant at the mine is of 1,000 k.w capacity at fifty periods when running at a normal speed of 1,500 r.p.m. (Trans. Inst. Min. Eng, Vol. XL., p. 302).

Class B. Winders working in connection with a load equaliser, the latter either taking the shape of an electrical device, such as a battery, or a mechanical device, such as a fly-wheel.

Class B (1) Battery Equaliser—The cases in which a storage battery has been used to equalise the load on a winding set are few and far between. The battery system is tempting, inasmuch as the losses with the battery only occur while it is being used, whereas with a fly-wheel equaliser the losses are constant and independent of the load

One of the earliest and most important instances of the use of the battery was Zollern II. Pit at Merklinde where Messrs. Siemens and Halske installed the system in the year 1902. The battery, which consisted of 250 cells of a 460 amp. hour capacity at a one-hour discharge rating, was divided into four groups of 125 volts each, with other subdivisions to give very slow speeds for shaft inspection. With all the cells in series and the battery in parallel with the generating station a rope speed of 49 ft. per minute was obtained, which could be increased to 65 ft. by reducing the excitation of the motor-fields. The battery was controlled by a commutator switch, which threw the groups into series or parallel and gave a large choice of speeds between 0 and 65 ft. per minute. The battery switch, in spite of the 2,000 amp. current which it frequently had to handle, gave no trouble, but the manipulation of the system left a good deal to be desired, and in 1904 it was superseded by the Ilgner Fly-wheel System and the battery kept as a reserve.

The system is however still in use at the Grangesberg Iron Mines in Sweden, designed by Mr. A. V. Clayton (Journal Inst. Elec. Eng., Vol. XXXVIII., p. 626), where power at 8,500 volts and 70 cycles is taken from a water-power station and is transformed down to 430 volts at a sub-station supplying the mine. A 400 h.p. synchronous motor-generator set supplies continuous current for the winder. A synchronous motor was adopted in order to improve the power factor, and on account of the difficulty of arranging a rotary converter for 70 cycles. The motor-generator runs continuously and charges

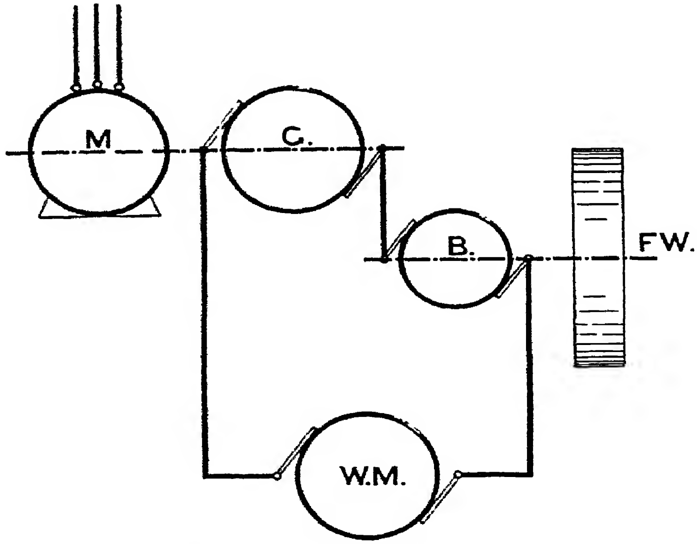


FIG. 65.—Crepelet system, connections.

243 Tudor cells, which have a capacity of 600 amp. hours at a high rate of discharge. The battery works in parallel with the motor generator when winding is in progress. Spiral drums are used and two motors, each of 600 h.p., with a maximum speed of 19 r.p.m. Their fields are compound wound, and at present they are connected in series and arranged for a mean rope speed of 10 ft. per second. The mine is 900 ft. deep, but later on will be deepened, when the motors will be connected in parallel and the mean speed will be 20 ft. per second. The winding motors are controlled by a resistance in the motor armature circuit, the switch being operated pneumatically

through a rack and pinion Complete control as to the direction of rotation and speed is obtained by one lever only.

Class B (2). The Crepelet System, the main feature of which is that the fly-wheel is placed in parallel with the load and driven by a motor, which is reversible and only supplies the energy for the peak during the acceleration period. It can therefore be smaller than if it had to supply the whole of the energy. Fig. 65 shows the arrangement diagrammatically. B is the motor or booster, which drives the heavy fly-wheel FW, and is connected in series with the winding motor WM and the supply system or generator G. The booster is wound for the same potential as the supply, and the winding motor is wound for twice this potential When the winding motor is idle its armature is short-circuited and the booster is connected across the generator, or supply system, and the speed of the fly-wheel is at its maximum To start the winder the short circuit on the motor is opened, the pressure of the booster is gradually reduced to zero, reversed and brought up to full potential in the opposite direction The booster then acts as a generator driven by the fly-wheel, and the power stored in the fly-wheel during the idle period is returned.

Various modifications of this important principle have been developed, such as the Westinghouse Rotor Converter System, as used at the Maritime Pit of the Great Western Colliery Co., South Wales (Proc. S. Wales Inst Eng Vol XXVI. p. 352). This winder is designed to handle 175 tons of coal per hour from a depth of 1,110 ft. at seventy winds per hour, which equals 5·6 tons of coal per wind.

The plant consists of a winding motor with a normal rating of 700 h.p., 2,200 volts, 25 cycles, at 56 r.p m.; a rotary converter with a normal rating of 400 k.w., which supplies continuous current at 550 volts pressure to the fly-wheel machine, and which is itself supplied at 350 volts by a transformer of 400 k.w.; and a fly-wheel machine consisting of a 250 k.w., 550 volt, continuous current motor at 500—750 r.p.m., coupled to a 10-ton fly-wheel which is 6 ft. in diameter. The control is effected by a liquid starting and reversing switch consisting of two tanks, one of which serves as the resistance, the other as the cooling tank. The blades are fixed and the

level of the liquid varied by the operation of the driver's lever. As mentioned elsewhere, this set is now operated without the fly-wheel.

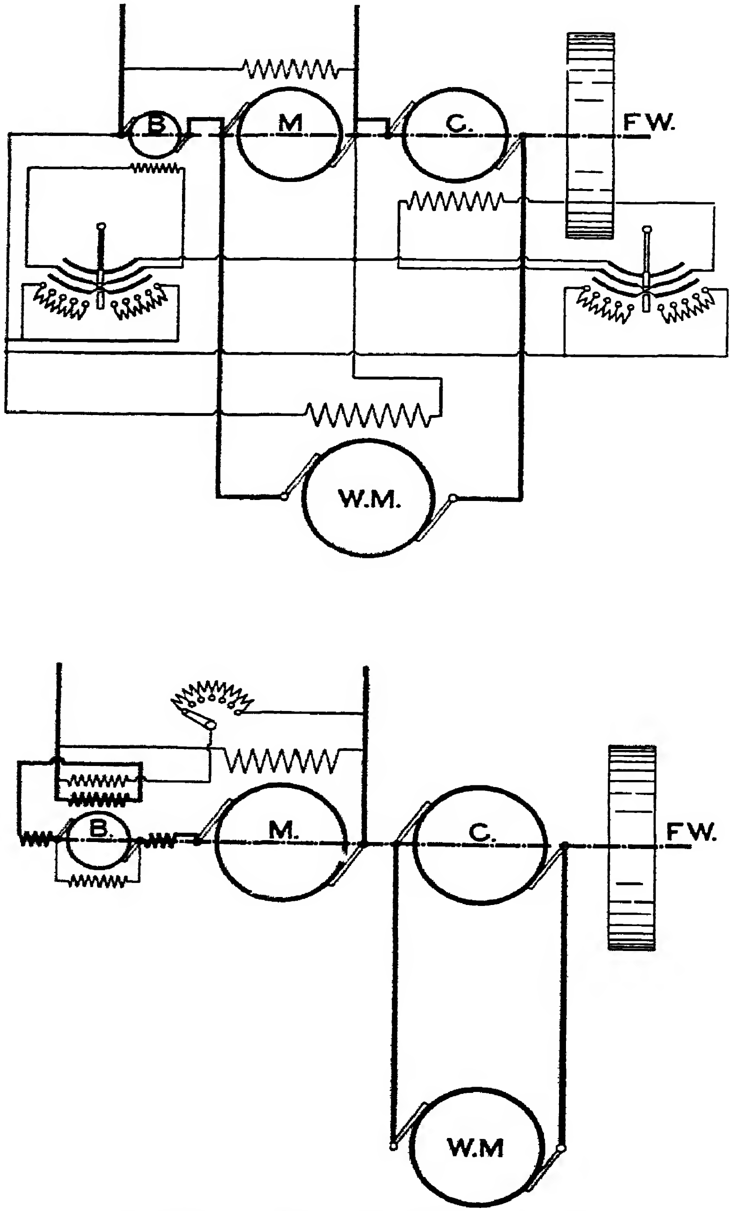


FIG. 66.—Lahmeyer systems, connections.

Class B (3). The Lahmeyer System, as used at Ligny-les-Aire, which was mentioned previously, p. 142, is shown in the upper part of Fig. 66. The equaliser set consists of three electric machines and a fly-wheel keyed on to a common shaft. When the winding motor W.M is at rest the starting dynamo G, which is connected in series with the line, has a voltage equal, but opposite in sense, to that of the supply. The pressure across the terminals of the winding motor is therefore at this period zero. When the winding motor is to be started the field of the dynamo G is gradually weakened, thereby increasing the pressure at the terminals of the motor. After the excitation of the dynamo has been completely suppressed the winding motor runs at half the normal speed. In order to further increase the speed the excitation of the dynamo is reversed and gradually strengthened It is obvious that by this process the pressure of the dynamo is added to that of the supply, the final voltage at which the motor is fed being double that of the supply. The driving motor M is shunt-wound and connected in series with the booster B on to the supply mains, by varying both the value and the direction of the voltage of this booster the speed of the equaliser may be regulated within 30 per cent., thereby enabling the fly-wheel to give out or to store energy as required. This speed variation is controlled automatically by means of a regulator connected in the main circuit. The action of this device is such that the speed of the equaliser is decreased and the load on the central station increased, and *vice versâ*.

Class B (4). The Lahmeyer-Kraemer system, a modification of the above, has also been developed by the same firm, and is shown in the lower part of Fig. 66. In this case the equaliser consists of the starting dynamo G, the driving motor M, and a special booster B, all three connected on to the same shaft as the fly-wheel; the driving motor is separately excited. The booster has a series field and a separately excited field wound to normally oppose and cancel one another. It is obvious that any change of current due to the speed fluctuation of the motor will disturb the field balance and cause one or the other to preponderate, thereby giving rise to a positive or negative tension at the booster terminals. This

tension is utilised to excite a third field winding connected as a shunt across the booster terminals. By means of this field any effect due to the disturbance of the balance between the series and the separately excited field is neutralised, and the line current is kept approximately at a constant value.

One advantage of this system is the absence of all automatic regulating apparatus ; as the booster is capable of giving a positive or negative boost it follows that for a pressure regulation of, say, 30 per cent. it will only be required to have an output of 15 per cent. of the driving motor.

Another feature of this system is that when lowering material into the pit the equaliser will regenerate and send current back to the line. An installation of this type is at work at the Ougrée Marihaye Pit in Belgium. The winder is provided with a drum of the reel type, and the motor has a maximum output of 2,000 h.p. as contrasted with the equaliser, which only takes 500 h.p. from the power station. The fly-wheel weighs 30 tons. The line pressure is 500 volts and the speed of the equaliser fluctuates between 350 and 500 r.p.m., with a corresponding fluctuation in tension from 440—660 volts, so that the booster supplies — 60 to + 160 volts.

Class B (5). The Thury System, where the generator on the fly-wheel set is placed in series with the motor. This system is especially suitable for collieries where more than one winder has to be driven, as the one equalising set serves for all, the winding motors being connected in series with one another which is the special feature of the Thury control. The speed regulation is effected by shifting the brushes on the commutator.

This system is employed at the Auchincruive Colliery, where two winders supplied by Messrs. Dick Kerr are situated one at each end of the house, which serves as a sub-station, and the motor generator set is located between them. The motor generator fly-wheel set consists of a 250 h.p., 2,750-volt, 50-cycle three-phase induction motor, coupled to a 10 ft. 6 in. fly-wheel, which weighs 4·7 tons. On the same shaft is a 450 k.w. constant-current series generator built to give 450 amps. at a voltage varying from 0 to 1,000 and to run at a speed varying from 375 to 428 r.p.m.

The induction motor is provided with a Thury slip regulator to limit the current taken from the alternating current supply. This regulator controls a resistance in the rotor circuit, and cuts it out automatically as the motor speeds up until the full speed is obtained. In the event of the load on the series generator increasing and the induction motor being overloaded the slip regulator inserts resistance in the rotor circuit, so enabling the fly-wheel to give out its stored energy. Each winder is driven through double-helical gearing made by the Power Plant Co., having a reduction ratio of 8·4 to 1. Each winder has a 275 h.p. constant current series motor; the winding drums are 10 ft. in diameter.

The speed of the motor is controlled by moving the brushes backwards or forwards from the neutral position, according to the direction of rotation desired. The brushes are controlled either by the winder attendant's lever or automatically by a relay gear operated by oil under pressure.

The depth of the pit is about 480 ft. Each winder is rated for a normal output of 600 tons in eight hours, the duration of the wind being 33 seconds and the maximum speed 27 ft per second for an average weight of coal per wind of one ton

Class B (6). The most commonly used of all is the Ward-Leonard-Ilgner Fly-wheel System, where the energy is taken from a fly-wheel generator which is driven by an induction motor from the supply mains. In this system the Ilgner motor-generator is connected in series with the load, so that it has to supply the whole of the energy required. An important advantage possessed by this system is that in the event of the main supply failing several winds can be completed by taking the energy out of the fly-wheel of the motor generator set.

One of the best examples of this system is to be found at the Ferndale Collieries in South Wales. It may be useful to set out the details somewhat fully and then consider a test which was carried out upon this winder.

The supply is taken from the owners' private power station. There is a Power Company in the district, but at the time that the order for this winder was under consideration they were not in a fit position to cope with the irregularities of a winder load unless damped down by equalising gear, so that the Ilgner

System was chosen as most suitable, no matter whether the supply was taken from the Power Company or from the private plant belonging to the owners.

The winder is of the cylindrical drum type and provided with a tail-rope for equalising the weights.

The prominent features of this plant are shown on Figs. G7, G8, G10, and G11.

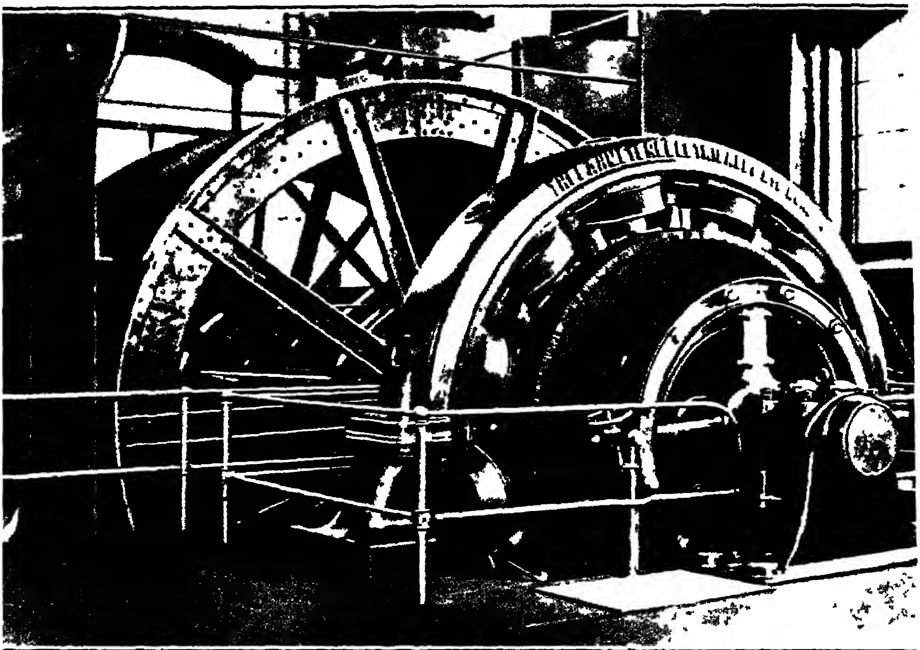


FIG. G7.—Winder at Ferndale Colliery.

Winding Drum.—The cylindrical drum (Fig. G7) has a diameter of 16 ft. and a tread of 9 ft. The centre part of the drum acts as a common path to both ropes. The extra wear and tear on the middle of the drum due to this double user is infinitesimal, and this construction is better practice than to make the drum so wide that such overlapping is not necessary. The drum shell, which is lagged with oak, is supported by wrought-iron arms, which are riveted to heavy angle-iron rings. At each end of the drum brake rings are fixed in such a manner that the brake pressure is taken directly by the arms.

The drum shaft is of mild, open hearth steel, while the motor shafts, which are coupled thereto, are of Siemens-Martin steel. The shaft rests in four bearings; the middle bearings, which carry the drum, are provided with special lubrication from an oil tank fixed on the engine-house wall. The two outer bearings which support the ends of the motor shafts only are provided with ring lubrication.

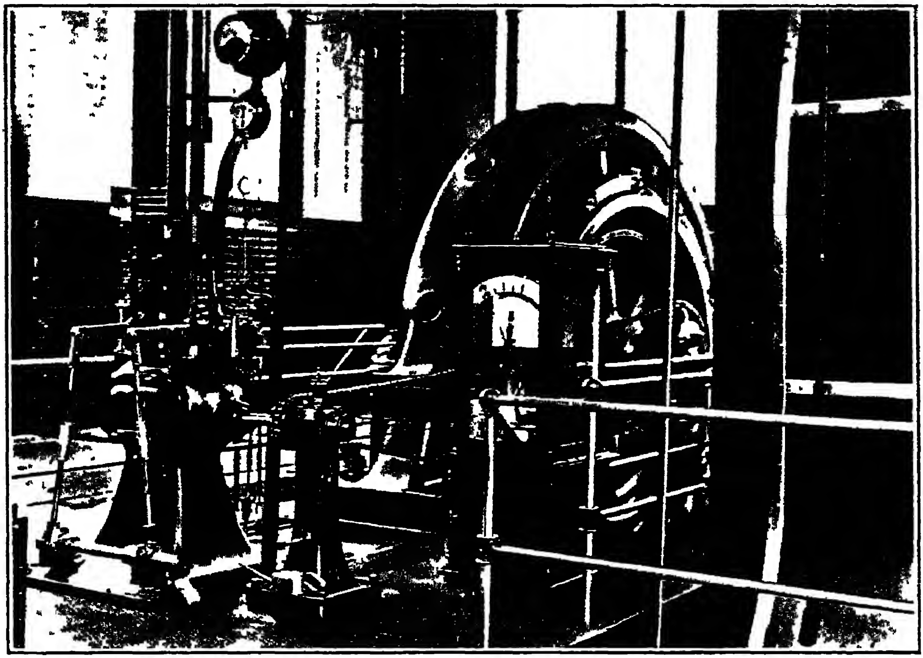


FIG. G8.—Winder motor with depth and speed indicators, Ferndale.

Brakes.—There are two sets of Whitmore post-brakes (Fig. G7), one on each side of the drum, which are so connected that they act both as emergency and working brakes. The brakes are of the falling weight type, the weight being lifted by an air cylinder controlled by a three-way valve connected to the lever on the attendant's platform. Under ordinary working conditions the brake is actuated by the attendant's lever. To actuate the brake under emergency conditions the turning of the three-way cock is automatically done by levers connected to the over-winding

device The brake weight when falling brings the interlocking gear into action, which moves the controlling lever into zero position.

The compressed air plant required for operating the brakes consists of a small air compressor driven by a 3 h.p. motor with an air vessel of suitable size, in which a pressure of 70 lbs. per square inch is kept up by an automatic governing device.

The brake acts as an emergency brake—

(1) When released by hand by means of the emergency switch placed in front of the attendant's platform ;
(2) When released by the depth indicator in the case of an over-wind ;
(3) When released by the brake magnet if the exciting current fails ;
(4) When the compressed air supply fails ;
(5) When released by the automatic cut-out in the main circuit.

In each case the controlling lever is brought back into the zero position and held there by a spring.

Depth Indicator.—The depth indicator (Fig 68) takes the form of a vertical column provided with two heavy square-threaded spindles, which are positively driven by chain gear from the drum shaft. The rotation of these spindles causes travellers carrying the indicators to move up or down and so show the position of the cages in the shaft at any moment. As the cage approaches the bank a rolling contact on the indicator traveller trips a lever and causes a gong to be sounded, which gives the attendant due notice to pull the controlling lever back to the zero position. Should the attendant fail to bring the lever back into the zero position a roller on the traveller comes into contact with the curved lever, which actuates a system of rods and links and thereby forces the controlling lever back nearly into the zero position, so automatically reducing the speed of the winder.

In order to prevent the attendant pushing the controlling lever over too rapidly and so accelerating at too high a rate, a retarding gear is provided which takes the form of a curved

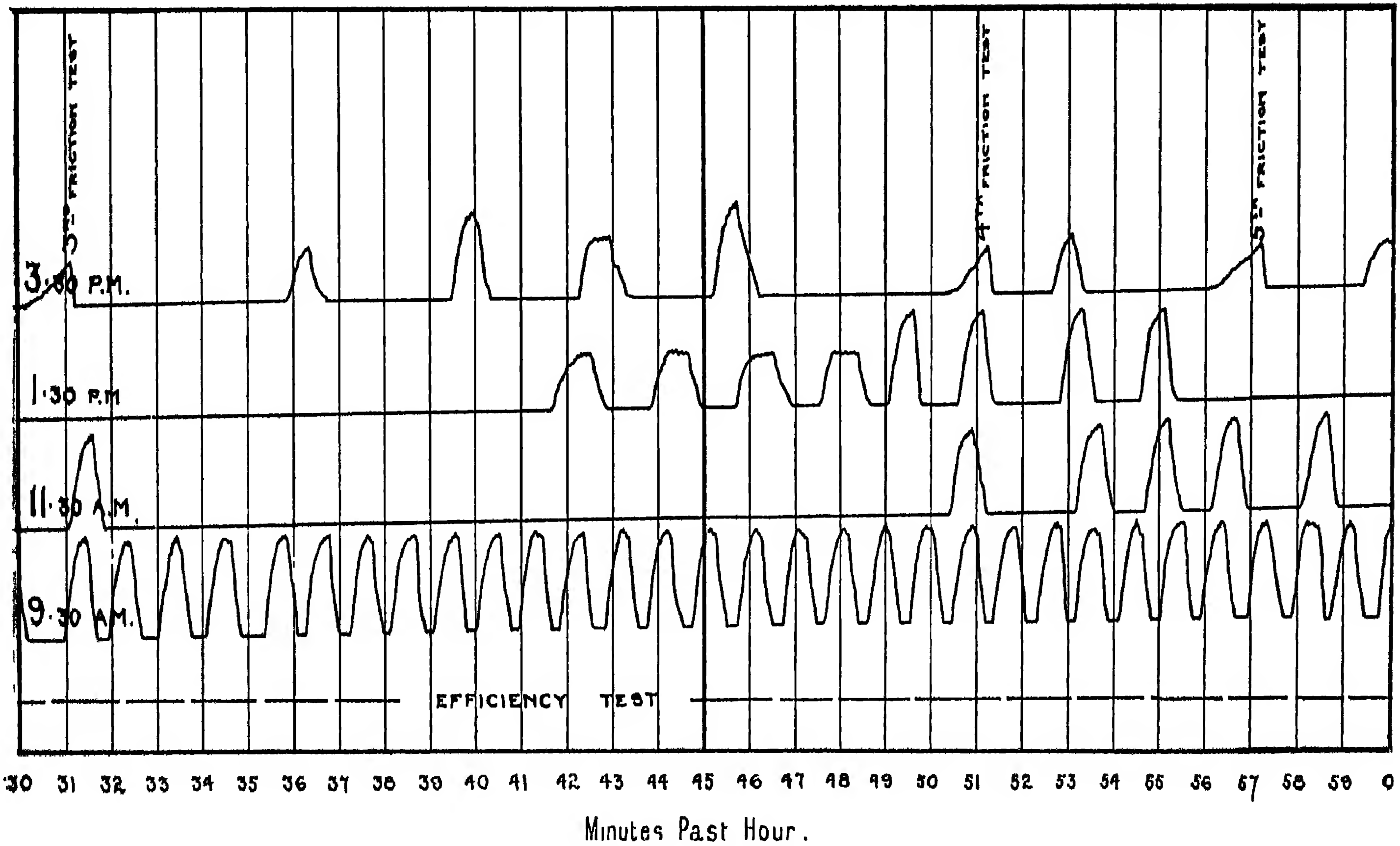


FIG. 69.—Karlik speed-indicator record.

lever in contact with the before-mentioned roller, so arranged that the roller has to be worked out of the way by the screwed spindle before the lever can be pushed over to the full-speed position.

In the event of an over-wind occurring the traveller on the depth indicator releases a catch, which by means of a system of links and levers causes the emergency brake to act, and at the same time opens the automatic cut-out and so cuts off the supply to the winder motors

The operation of the automatic cut-out closes a relay circuit, which interrupts the supply of current to the brake magnet, so that its core falls, causing the emergency brake to come into action.

It is sometimes necessary to wind the cage above the normal level, and to allow this to be done a spring-catch is fitted on the emergency lever, which can be raised and the desired over-wind effected.

In order to prevent the possibility of the attendant throwing the controlling lever right over while the brakes are applied, when the brake is put on it pulls the curved lever over and so indirectly interlocks the controlling lever. The depth indicator standard also carries an ammeter, volt-meter, and an air pressure gauge, thus showing the attendant the condition of his plant at a glance.

Speed Indicator.—A Karlik Tachograph, or recording speed indicator (Fig. 68), which gives a complete continuous record of the number of winds and the speed of each wind throughout the day, is driven by a small belt from the depth indicator spindle. The scale of the record is such that a rope speed of 110 ft. per second corresponds to a height of diagram of 1 in. The chart is about 3 ft. 6 in. long; the drum upon which it is mounted is controlled by a spiral thread, which allows it to fall about 1¼ in. per revolution. One revolution takes two hours, and the paper gives a continuous 24-hour record. Fig. 69 is a reproduction of a portion of a chart, and shows a record of winding during four ½-hour periods.

Winder Motors.—The winder is provided with two motors directly coupled one on either side of the drum shaft (Figs. 67,

G8). Each machine consists of a separately excited 250 volt 1,000 h p. motor, having twelve main poles and provided with inter-poles to prevent sparking at the brushes. The machines are connected in series, and can be run with 4,000 amps. in one direction down to zero, reversed, and run up to 4,000 amps. in the other direction, with fixed brush position and no sign of sparking at the brushes.

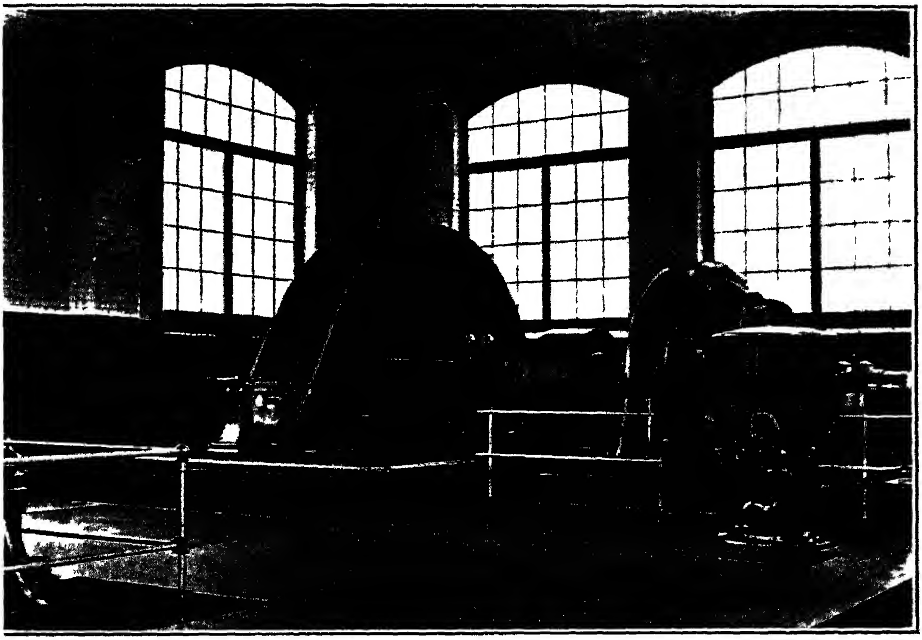


FIG G10.—Ilgner set, Ferndale; showing fly-wheel.

Ilgner Motor Generator.—In order to overcome the fluctuations from zero to 1,200 h.p. an Ilgner Fly-wheel Motor Generator set is provided, which stands at the end of the engine-room at right angles to the winding drum shaft, as shown in Figs. G10, G11. The duty of such a motor generator set is to store the energy given out by a three-phase motor, during the periods when no current is required by the winding motor, in a fly-wheel mounted on the same shaft as the three-phase motor and a continuous current dynamo which supplies the current to the winding motors. The energy given out by the fly-wheel

is utilised when starting the winding motors, as the demand then is far in excess of the average output required for the wind.

To enable the fly-wheel to give out its energy it is, of course, necessary that the speed of the motor generator should decrease. When no more power is required by the winding motor, *i.e.*, during the period of retardation of the winding motors, the

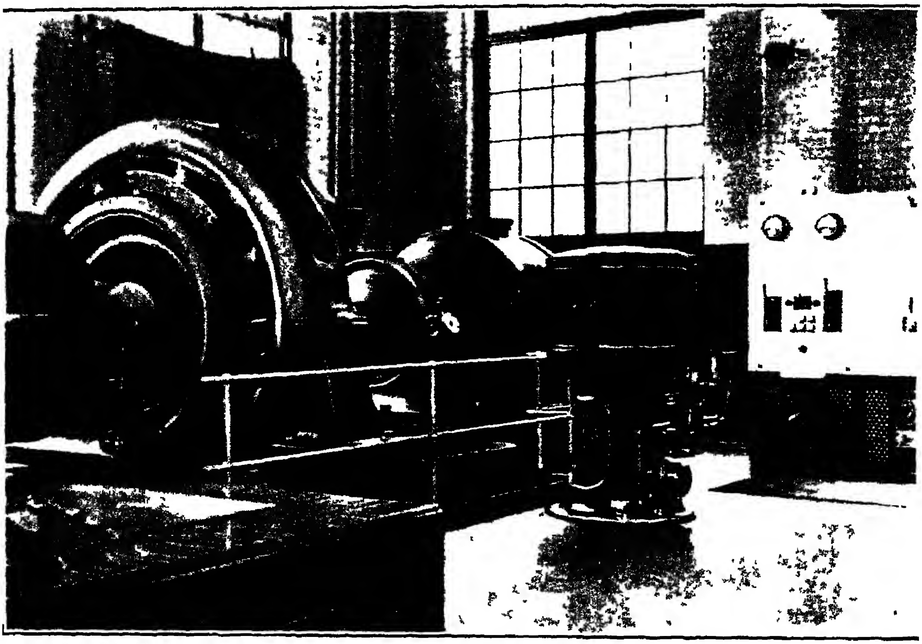


FIG. G11 —Ilgner set and speed regulator, Ferndale.

three-phase motor speed increases, so increasing the speed of the fly-wheel and restoring energy therein.

The motor generator set consists of :—

An induction three-phase motor with an output of 700 h.p. at 500 to 425 r.p.m., which takes energy at 2,200 volts as generated by the power station.

A continuous current dynamo designed for 500 volts and furnished with compensating poles, the exciting voltage of which is 220 volts, but can be raised to 240 volts for regulating purposes.

A flexible coupling of the Zodel Voith type inserted between the three-phase motor and the generator.

A clutch of the magnetic type inserted between the generator and the fly-wheel, so that the motor and generator can be run with or without the fly-wheel

Fly-wheel.—The fly-wheel which is used to equalise the load has an outside diameter of 12 ft. with a width of face of 2 ft. 6 in., and weighs 30 tons. The peripheral speed is 105 yards per second. It is turned all over so as to reduce the air friction losses, and is covered with a wrought-iron casing.

The fly-wheel shaft runs in heavy bearings provided both with ring lubrication and forced lubrication The oil pressure under the bearings is about 150 lbs. per square inch at starting and 50 to 60 lbs. when the fly-wheel is running. Contact thermometers and an electric alarm bell circuit are provided to indicate any abnormal rise of temperature in the bearings (Fig. G12).

Fly-wheel Brake.—In order to stop the fly-wheel in case of emergency a Foucault Magnetic brake is provided, by which the fly-wheel can be stopped in about seven minutes.

Slip Regulator.—In order that the fly-wheel may give up its stored energy during the fluctuations of the load an automatic slip regulator is provided, which switches resistance into the rotor circuit of the three-phase motor as the over-load comes on.

The contact apparatus is in the form of an induction motor, the stator frame of which is pivoted so that it is capable of partial rotation, and is kept in position by means of controlling springs. The rotor of the contact apparatus is driven by means of a flat link chain direct from the motor generator shaft, and is connected to the high tension network through a transformer. The stator is connected in a similar manner to the slip-rings of the three-phase motor. The smallest speed variation of the main motor causes a corresponding variation in the speed of the rotor of the contact apparatus. This speed variation determines the position of the floating stator, which makes contact

at each end of the limited path through which it can travel, and so energises the magnetic circuits on the resistance switch.

The resistance switch consists of a contact switch in the form of a commutator with a vertical spindle (Fig. 611), the separate segments of which are connected to the metallic resistances, which are fixed in the basement To prevent the destruction of the contact brushes the switch is provided with three rollers which act as sparking pieces. In the foot of the standard carrying the commutator switch is placed a small motor which drives a rocking wheel upon the edge of which broad teeth are cut. Over the edge of this wheel a pair of double magnets are centrally mounted with pawls attached to their armatures. When no current is passed through the magnets both the pawls are disengaged from the teeth of the wheel, but as soon as one of the magnets is energised by the circuit having been made at the contact apparatus, its corresponding pawl engages with the wheel and so causes the commutator switch to revolve until the contact is broken and the pawl released by the magnet.

The slip-regulator can be adjusted so that the time during which the energy in the fly-wheel is restored can be varied. When rapid winding is in progress the fly-wheel must be recharged with energy more quickly than when, as during slack times, only occasional winds are required, so that by this apparatus not only are fluctuations due to the winder diminished by the action of the fly-wheel, but the fluctuations due to charging the fly-wheel itself can be regulated and controlled.

The magnetic coupling between the fly-wheel and the dynamo enables the motor generator to be run either with or without the fly-wheel. It is important in sets of this description to remember that the coupling is only closed when both the fly-wheel and the motor generator are standing still.

Exciter Motor Generator.—For the excitation of the winding motors and of the generator of the Ilgner set, a separate motor generator is provided. This set has an output of 25 k.w., and runs at 750 r.p.m. It also provides current for the air compressor motor and for the oil pumps.

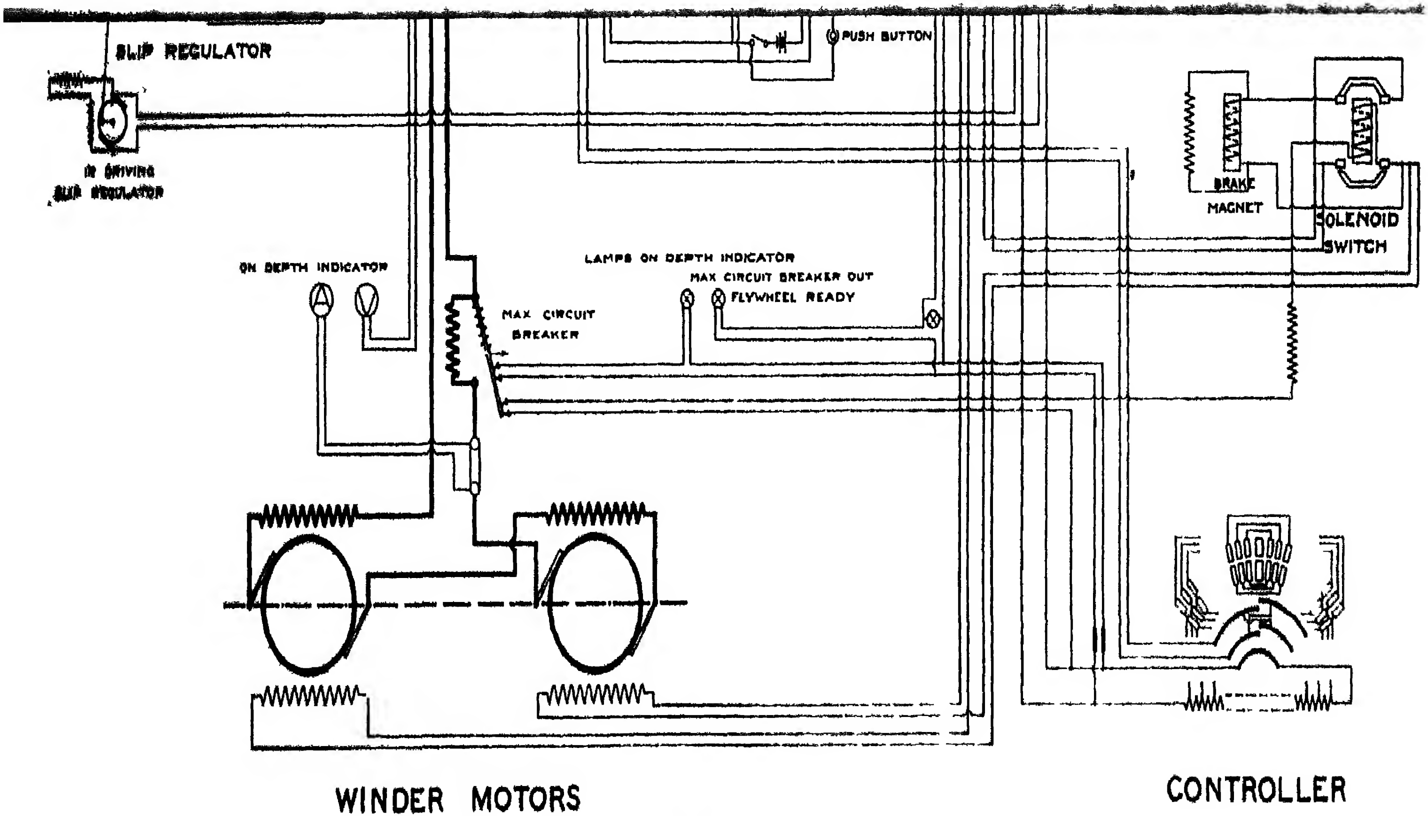


Fig. 612. Diagram of connections, Ferndale winder.

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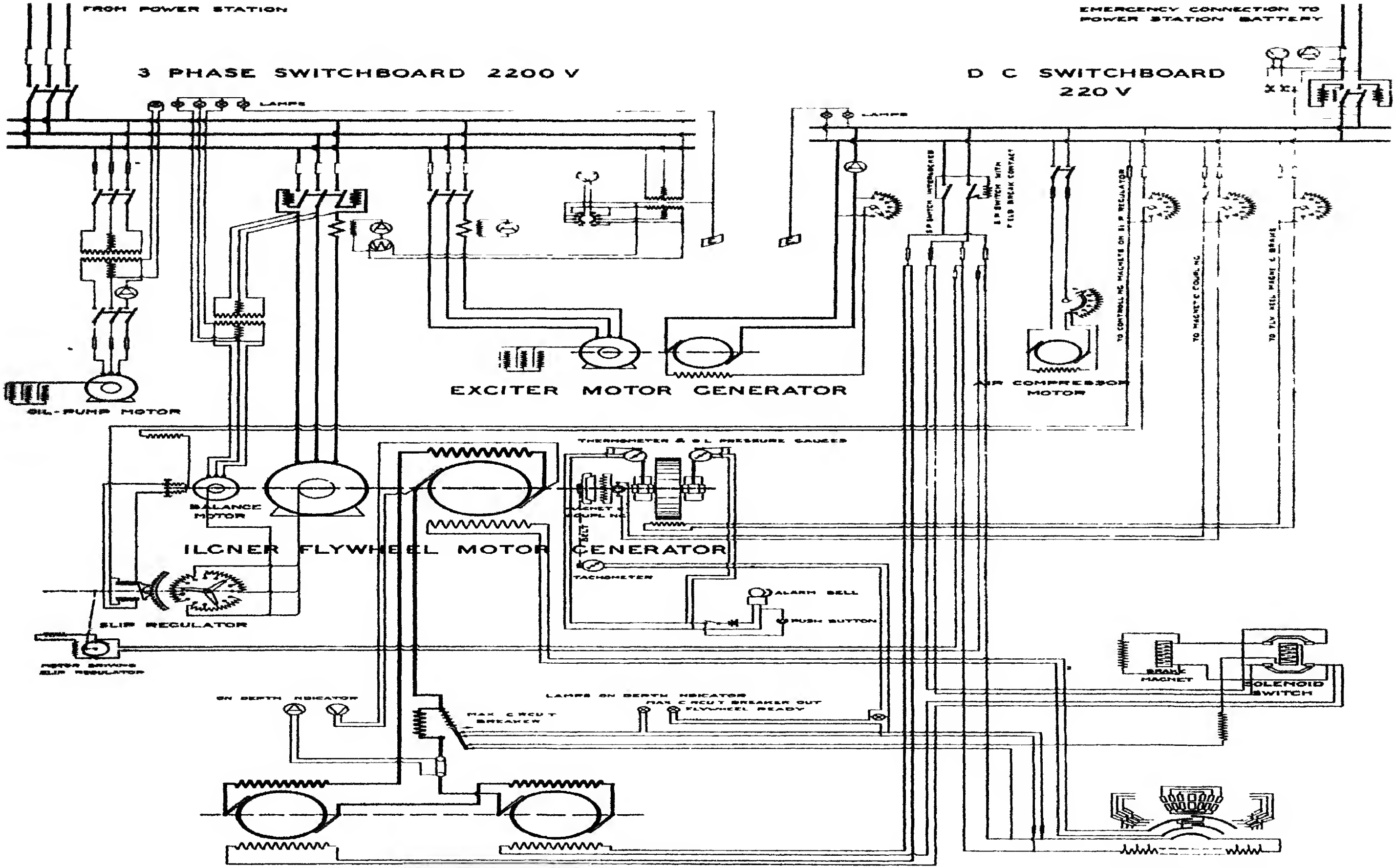


FIG. 112 Diagram of connections, Ferndale winder

To face page 180.

Switchboard.—The switchboard consists of five panels, the high tension gear being of the usual three-phase oil switch type. The panels are allocated as under :—

(1) Continuous current circuits for excitation ;
(2) Continuous current circuits for pump motors ;
(3) Exciter motor generator three-phase switchgear ;
(4) Fly - wheel motor generator three-phase switch-gear ;
(5) Incoming feeder switch-gear.

Connections.—A complete diagram of the connections of the Ferndale Winder is shown in Fig. G12.

Operation.—The important feature in this winding plant is its immunity from the effects of faulty manipulation on the part of the attendant so long as the working parts are in proper order. The direction of rotation of the drum is regulated by the position of the controlling lever, a suitable contact on which reverses the current in the field of the continuous current generator of the motor-generator set. The safety devices allow the attendant a free hand so long as he keeps within the prescribed limits. So soon, however, as he oversteps the mark, either by running at too high a speed or neglecting to slow up at a proper time, the safety devices act. The human element is therefore eliminated as much as possible, and danger from faulty manipulation is avoided.

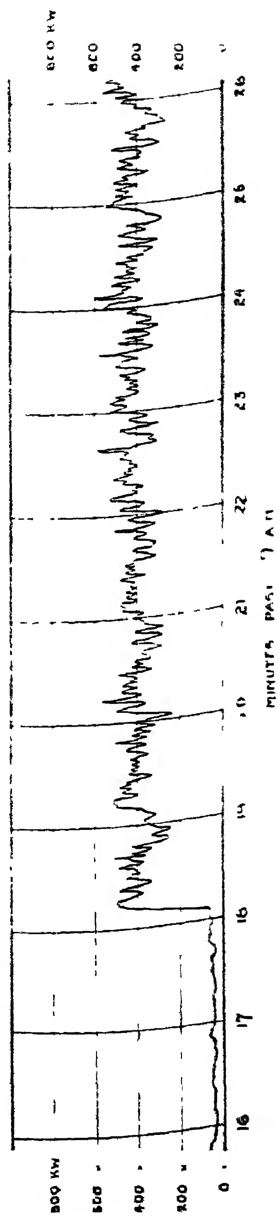


Fig. 613. Watt meter record, Ferndale winder.

In order to demonstrate the reliability of the safety devices the winder has been

repeatedly started up and then left to complete the wind automatically, which it did invariably without the slightest irregularity.

Fig. G13 is a portion of a recording watt-meter chart, which

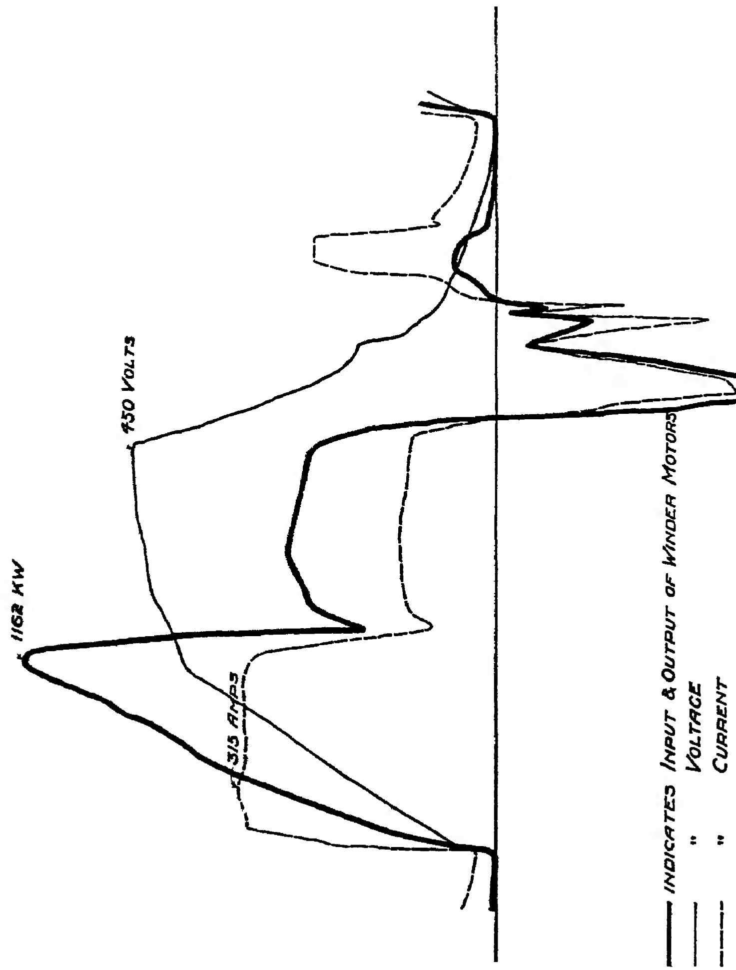


FIG. G14.—Energy curve for one wind, Ferndale.

shows the total input to the winder under no load and full load conditions.

Fig. G14 shows a record of a typical normal wind.

The schedule of particulars to which the plant was ordered is given in Table G2.

TABLE G2.

Depth of wind	560 yards.
Output per day of nine hrs.	1,800 tons
,, ,, wind . ..	3 ,,
Maximum speed	63·2 ft. per sec.
Accelerating rate	2·815 ,, ,, per sec.
Retarding rate	4·39 ,, ,, ,,
Average speed	37·5 ,, ,,
Duration full speed.. ..	8·15 secs.
,, accelerating ..	22·45 ,,
,, retarding	14·4 ,,
,, banking	10 ,,
,, of complete wind	55 ,,
Rope circumference ..	5½ in.
,, weight per yard ..	15½ lbs.
Weights—	
Cage and bridle	10,500 lbs.
Two trams	2,240 ,,

Messrs. Lahmeyer, who were the contractors for the plant, gave the following guarantees :—

Winder working at Full Load.

Consumption of energy ..	575 B.T.U. per hour, with a 4 per cent. margin.

Fly-wheel Set.

Energy to be taken by the fly-wheel set when the winding drum is standing but all the auxiliaries working, not to exceed	67·6 B.T.U. per hour, with a 10 per cent. margin.

The winder was ordered while the shaft was being sunk, and as the depth originally contemplated was not quite reached, a correction has to be made for the actual depth, 516 yards instead of 560 yards. The acceleration and retardation being the same as that contemplated in the contract, the decreased

distance to be travelled is taken out of the part of the journey which is run at top speed, and as the top speed is 62·3 ft. per second, the difference between the intended and the actual depth of 44 yards calls for a reduction of 2·115 seconds in the time of the wind, making the duration of the complete wind 52·88 seconds including banking, instead of 55 seconds, as contemplated in the contract.

Tests.—A consideration of the tests, taken to ascertain whether the winder complied with the guarantees, will bring out a few important points, so may be useful.

Energy taken at Light Load.—Several tests were taken to determine the energy drawn from the mains when the drum was standing, with the fly-wheel set and the auxiliaries running. The average showed 66 k.w. per hour, which compared favourably with the guarantee of 67·6 with a 10 per cent. margin.

Full Load Test.—In a new pit, owing to the restricted space, it is difficult to store the amount of coal necessary to provide a full load test for a winder.

Preparations had been made and coal had been accumulated near the pit bottom in view of the test. During the test fifty winds were made, as recorded by the Karlik Indicator. Each wind consisted of two wagons of coal ; the total weight of coal, as recorded by the official weigher, was 134 tons. The average weight of coal per wind was therefore 2·68 tons instead of 3 tons, as contemplated by the contract.

Correcting the full load guarantee for the difference in the depth of the pit between the actual conditions and the conditions upon which the guarantee was based, the following figures are arrived at :—

Corrected guaranteed energy per hour ..	585 B.T.U.
,, ,, ,, ,, wind ..	8·23 ,,
,, ,, , ,, ton of coal	2·74 ,,

with, of course, the margins provided in the contract.

The result of the test corrected for full 3-ton loads showed

Energy consumed per wind	7·77 B.T.U.
,, per ton of coal	2·59 ,,

which showed a performance $5\frac{1}{2}$ per cent. better than the guarantee.

Table G3 shows a summary of the test :—

TABLE G3.

Time		Seconds			Tons of Coal Wound.		Guarantee Corrected for Depth			[illegible]		
From	Till	Mean per Wind	Quickest Wind Made	Guaranteed Corrected Time	Total	Per Wind Mean	Per Hour B.T.U.	Per Wind B.T.U.	Per Ton B.T.U.	Per Hour B.T.U.	Per Wind B.T.U.	Per Ton B.T.U.
Saturday 12th June 1909												
9 18 15	10 6 0	57.3	51.5	53	134	2.68	558	8.23	2.74	528	7.77	2.59

Shaft Friction.—The contractors' guarantee was based on a shaft drum and rope efficiency of $82\frac{1}{2}$ per cent., which means that $17\frac{1}{2}$ per cent. of the total power in winding would be absorbed by friction. This friction opposes motion, and, as previously mentioned, can be expressed in lbs. weight. The guarantee was based on a friction equivalent to 1.426 lbs. weight lifted, and the total dead load on the winding rope would be 6,720 lbs. + 1,426 = 8,146 lbs., when 3 tons of coal are wound. In order to determine the actual friction a special series of tests was carried out.

The ascending cage was loaded with two empty wagons and the descending cage with two wagons containing a known weight of stone. The brakes were then released from the drum and the loaded cage allowed to travel freely down the shaft. The time was taken when the drum commenced moving, and then again after a definite number of revolutions.

If M = the total mass in motion, reduced to the rope,
W = the weight of the stones,
F = the friction,

then $W - F$ is the accelerating force, and the rate of acceleration A_{acc} =

$$\frac{W - F}{M}$$

The travel S during T seconds is equal to

$$\frac{A_{acc} \times T^2}{2}.$$

As S and T are known, A_{acc} may be calculated, and equals

$$\frac{2 \times S}{T^2}.$$

M, W, and A_{acc} being known, the friction f is obtained from the equation

$$A_{acc} = \frac{W - F}{M}.$$

Three tests were made with the stone-loaded wagons in one cage, and then in the other cage, so that any out-of-balance effects would be cancelled out.

Test 1.—The drum made 12 complete revolutions in 74 seconds. The length of rope corresponding to one revolution is equal to 50·3 ft., therefore the acceleration = 0·22 ft. per second per second.

In this test the Karlik Speed Diagram showed that the acceleration was not uniform—in other words, the friction varied due to the brake sticking on the drum.

Test 2.—The drum made 11 complete revolutions in 48 seconds, hence

A_{acc} = 0·479 ft. per second per second.

Test 3.—The drum made 13 complete revolutions in 64 seconds, hence

A_{acc} = 0·318 ft. per second per second.

Test 4.—The drum made 12 complete revolutions in 55 seconds, hence

A_{acc} = 0·399 ft. per second per second.

Test 5.—The drum made 16 complete revolutions in 73 seconds, hence

A_{acc} = 0·302 ft. per second per second.

Test 6.—The drum made 15 complete revolutions in 62 seconds, hence

A_{acc} = 0·392 ft. per second per second.

The nett weight of stones in the wagons was 2,639 lbs. Discarding the first test, when the brake stuck, the average acceleration is found to be 0·38 ft. per second per second, and from this figure the total shaft friction works out as 1,236·7 lbs.

The guarantee was based upon 17½ per cent. of the total power used in winding, which would be 1,426 lbs.

The total dead load on the rope during winding was therefore

TABLE 64.—TYPICAL ELECTRICALLY-DRIVEN WINDERS.

Class No.	Locality	When started	Duty: Depth, yds	Duty: Useful load, tons	Duty: Tons per hour	Duty: Max speed, ft per second	Mechanical Details: Type of drum	Mechanical Details: Drum, diameter ft	Mechanical Details: Rope diameter, inches	Mechanical Details: Drive	Electrical Details: Supply	Electrical Details: Control	Electrical Details: Motor output, h p	Electrical Details: Motor speed, r p m
	Without Equaliser.													
A_1	Preussen II, Dortmund .	1902	765	2 2	100	52 5	Koepe	19 5	$1\frac{11}{16}$	Direct coupled	3-phase, 2,000 v, 50 ~	Rheostatic	1,380 max	52 [illegible]
,,	Grand Hornu, Belgium .	1904	1,090	2 6	65	36	Reels	4 1 – 21 [illegible]	Tapered	,,	3-phase, 1,250 v, 23 5 ~	,,	910 ,,	—
,,	Harton Coal Co, Durham	1910	434	—	—	36	Cylindrical	14 25	—	,,	3 phase, 6,000 v, 40 ~	,,	1,700 ,,	51
,,	East Rand Prop Mines, S Africa	1909	1,000 incl	3	87	50	,,	8 5	1	,,	3-phase, 3,000 v, 25 ~	,,	1,700 ,,	112
A_3	Czeladz, Poland . .	1911	109	1 6	100	20	Spiral	10 3 – 9	–	Single reduct double helical	3-phase, 500 v, 50 ~	Brush-shifting	280 ,,	230
A_4	Koenigshutte, Upper Silesia	1909	206	2	108	33	Koepe	14 5	$1\frac{5}{8}$	Direct coupled	3-phase, 6,000 v	Ward Leonard	300 ,,	21 4
A_5	New Modderfontein, S Africa	1909	1,335 incl	3 67	70	33	Cylindrical	8	$1\frac{1}{4}$	Single reduct	C C, 500 v	Series-parallel	2 [illegible] 750	79
A_6	Heinitz, Upper Silesia .	1909	840	7		3[illegible]	Koepe	26 25	-	Direct coupled	,,	Ward Leonard		23 [illegible]
	With Equaliser													
B_1	Zollern II, Merklinde	190[illegible]	-	--		65	-	-	--			-		--
,,	Grangesberg, Sweden	1902	300	7[illegible]	1,[illegible]00 per diem	10	Spiral		—	Direct coupled	C C, 130 v	Series-parallel	2 × [illegible]00	-
B_2	Great Western Collieries, S Wales	1908	367	[illegible]	[illegible]	40	Spiro cylindrical	[illegible]	$1\frac{1}{4}$	,,	3-phase, [illegible],[illegible]00 v, 25 ~	Crepelet-Westingh'se	700 normal	
B_3	Lagny les Aire, France .	1904	138	[illegible]	10[illegible]	[illegible]	Koepe	[illegible]	$1\frac{3}{8}$	,,	C C, 500 v.	Lahmeyer B'ster contl	2 [illegible] 300	[illegible]
B_4	Ougree Marihaye, Belgium	1908	1,100	[illegible]	48	16	Reels	8 1 – [illegible]	Tapered	,,	,,	Lahmeyer-Kramer B'ster contl	2,000	
B_5	Auchincruive, Scotland	1911	160		[illegible]	27	Cylindrical	10		Double helical gear	3-phase, [illegible] v, 50 ~	Thury control	2[illegible]	51 [illegible]
B_6	Ferndale Collieries, Tylorstown, South Wales	1908	510	3	[illegible]00	63	,,	16	$1\frac{1}{4}$	Direct coupled	3 phase, [illegible],[illegible]00 v, [illegible]0 ~	Ward Leonard-Ilgner	[illegible] × 1,000	[illegible]

2·68 tons of coal + 1,236·7 lbs., equivalent friction = 7,237 lbs., and the shaft efficiency = 82·69 per cent.

It is often difficult to run a test in a generating station owing to the staff engaged not being accustomed to the work, but when the test not only includes new machinery but includes new men and a new pit, the difficulty in getting everything to run like clockwork is enhanced, but the result of these tests was considered very satisfactory.

Summary Table.—For convenient reference the leading particulars of examples of each of the twelve types enumerated are given in Table 64. The twelve types are not exhaustive, as other varieties exist, but suffice to give a general idea of the way in which the problem of electric winding is being solved.

CHAPTER VIII

VENTILATION AND AIR COMPRESSING

Ventilation.—The reason for ventilating mines is to make the air suitable for working in, both as regards its purity and temperature. The impurity may be due to gases given off by the ground through which the workings are driven, or it may be due to the products of combustion of the explosives used. The temperature is due to the natural increase in the temperature of the earth, which is at the rate of about 1° F. for every 70 ft. in depth below 50 ft. from the surface. There is no definite rule as to increase by which the temperature which would be met in any particular pit can be calculated.

In South Wales the average rate of increase varies from 1° F. in 76 ft. to 1° F. in 95 ft.

In Lancashire it varies from 1° F. in 60 ft. to 1° F. in 80 ft.

The hottest normal temperature in any coal mine in the United Kingdom is stated by Mr. R. A. S. Redmayne, in his "Modern Practice in Mining," Vol. IV., p. 20, to be at Pendleton Colliery, where 94° F. is recorded at a depth of approximately 3,245 ft. The same writer also records a temperature of 84° F. at a depth of 3,772 ft. in a Belgian mine.

A visit to a Turkish bath easily establishes the fact that hot, dry air can be breathed with much less inconvenience than a damp atmosphere which is at a much lower temperature. The physiological effect of moisture in the air at different temperatures has been the subject of much investigation, and it appears to be agreed that working in saturated air at 75° F. is difficult; at 95° F. it is impracticable, although men can work in dry air of 100° to 120° F. in temperature.

The Coal Mines Act, 1887 (section 49, rule 1), called for such adequate ventilation as would dilute and render harmless any gas given off without establishing any standard of either ventilation or impurity.

The Coal Mines Act, 1911, section 29 (3), establishes a standard of purity—the air must not contain less than 19 per cent. of oxygen or more than $1\frac{1}{4}$ per cent. of carbon dioxide, but it prescribes no limits of temperature or moisture.

This legislative direction is interesting and important in view of the statement made by Dr. J. Harger in papers read by him in January and February, 1912, on "Dust Explosions and their Prevention," before the Liverpool Section of the Society of Chemical Industry, and the Manchester Geological and Mining Society in Manchester. Dr. Harger, after referring to facts relating to combustion and respiration, stated that while neither a candle nor an ordinary oil lamp would burn in air in which the oxygen was reduced to 17 per cent., a man could do continuous hard work in such an atmosphere and not notice any difference from ordinary air No shortage of oxygen is noticed until the proportion is reduced to below 14 per cent. At 12 per cent a shortage was marked, at 10 per cent. a dangerous point is reached, and at $7\frac{1}{2}$ per cent. life is extinguished, just as a candle is extinguished at 17 per cent.

Dr. Harger has been studying the question for some time, and has formed a hypothesis that the oxygen percentage of the air is a vital factor in dust explosions. He has tested his theory by actual experiments, and finds that a reduction in the oxygen necessary to prevent explosions varied with the different coals and with the method of working. In most mines a reduction of 1 per cent. in the oxygen suffices; in others a reduction of nearly 2 per cent. of the oxygen with nearly $\frac{3}{4}$ per cent. of carbon dioxide was necessary to render them safe. Absolute safety was secured if the reduction in oxygen was made to $17\frac{1}{2}$ per cent. with $\frac{1}{2}$ to 1 per cent. of carbon dioxide, not only from coal-dust explosions, but from fire-damp explosions. Such atmosphere, he states, is as good as ordinary air for respiration. If these laboratory and provisional experiments are corroborated by experiments on a larger scale they will point to the advisability of less ventilation in the mines.

In his "James Forrest" Lecture (Proc. Inst. Civ. Eng., Vol. CLXXXVI., p. 389), Dr. Hatch states that the South African Mining Regulations compel a supply of 70 cub. ft. of pure

air per man per minute to be sent into the mine, but owing to the difficulty of enforcing this standard an attempt is being made to get the quantity regulation varied in favour of a quality standard.

Systems of ventilation by natural draught, by furnaces, and by slow-speed fans driven by steam engines are gradually giving way to ventilation by high-speed fans, which lend themselves well to electrical driving. In some quarters the driving of ventilating fans by electric motors is not received with favour, as the steam engine has been considered more reliable than an electric motor, and the long user of the fan is in favour of a steam engine, as the steady load eliminates stand-by losses and so discounts the saving due to electric driving.

An up-to-date steam engine and boiler equipment will develop a brake horse-power hour on a fan shaft for less coal than would be necessary to develop the same power generated and transmitted electrically Electric driving, however reduces the cost of the labour in attending to a fan but the chief reason for driving fans electrically is most appreciated when their steady load is combined with the intermittent load of haulages, &c , and the effect of the joint load-factor on the power station is considered

H M. Chief Inspector of Mines, Mr R A. S Redmayne in his Report on the Explosion at Hulton Colliery in December. 1910 (Cd 5692, p. 37), states —

" In my opinion it is inadvisable to drive the main mechanical ventilator of a mine by an electric motor of fixed speed. A fan cannot be regarded as an apparatus which is subject to an unvarying speed; it may at any moment be found necessary to considerably increase or decrease the number of its revolutions, depending on the condition of the mine, for which purpose steam is the most adaptable power, and it is well to have a spare or stand-bye engine in case of breakdown, a fact well recognised and carried out in some instances."

Granted, a fan is not to be regarded as an apparatus to be run at a constant speed, or rather that it must be so arranged that it can readily and economically deliver varying quantities of air as may be called for by the conditions of the mine. In

a large fan this means that speed regulation must be provided of such a nature that the fan can readily deliver more or less air than the normal quantity. In small fans, such as are used for auxiliary ventilation. the conditions may be economically met by throttling. There is no difficulty in regulating the speed of a continuous current electric motor. In his Report, above quoted. Mr. Redmayne would appear to have had in mind polyphase motors, which at one time were considered unsuitable for fan driving. due to their constant speed The author, however, showed some years ago (Proc. S. Wales Inst. Eng., Vol. XXVI., 1909) that this defect could be got over comparatively easily. Since he adopted the method of regulation described later, it has been freely used, and now the Sandycroft Cascade Motor (p. 161. *ante*) has been developed, it. as well as other systems which will be mentioned, appear to offer considerable advantages in this direction.

Mechanics of Ventilating Fans.—In order to fully appreciate the difficulties encountered in driving a fan by an electric motor it is necessary to briefly review the characteristics of fans in general. There are three fundamental laws governing fans, viz.—

For constant resistance or orifice	(1) The air discharge varies as the tip speed of the fan; (2) The gauge reading varies as the square of the speed; (3) The power varies as the cube of the speed.

In practice it is found that the power does not vary quite as the cube of the speed. Tests show that the variation is more closely as the 2·5th power of the speed.

To calculate the air h.p. of a fan, the following formula is used :—

$$\text{Air h.p.} = \frac{V_a \times WG \times 5{\cdot}2}{33{,}000},$$

where V_a = the volume of air delivered in thousands of cubic feet per minute,

and WG = the water gauge in inches.

The 5·2 is explained by the fact that a cubic foot of water at 62° F. under 30 in. barometer pressure weighs 62·355 lbs., consequently the pressure per square foot due to each inch water gauge is $\frac{62\cdot355}{12} = 5\cdot196$ lbs., or, rounded off, 5·2 lbs.

The b h.p. of a fan = air h.p. divided by the efficiency of the fan.

The general formula governing air velocity is the same as the law governing the velocity of falling bodies, viz., $v = \sqrt{2gh}$.

Murgue's Equivalent Orifice.—Mr. Murgue (Bulletin de la Société de l'Industrie Minérale, Series 2. 1873) compared every mine to an orifice in a thin plate, which he called the "equivalent orifice." By this means all existing mines can be compared by the sizes of their orifices. The equivalent orifice of a mine=

$$O = 0\cdot403\,\frac{V_0}{\sqrt{h}} = \frac{V_0}{60 \times 0\cdot65\sqrt{2g\,\frac{h}{12} \times \frac{d_3}{d_2}}},$$

where $\sqrt{2g\,\frac{h}{12} \times \frac{d_3}{d_2}}$ stands for velocity v.

The formulæ connecting the orifice with the quantity of air and the WG as generally stated are—

$$(a)\quad O = \frac{0\cdot4\,V_0}{\sqrt{WG}},$$

$$(b)\quad V_0 = \frac{O\sqrt{WG}}{0\cdot4},$$

$$(c)\quad WG = \left(\frac{0\cdot4\,V_0}{O}\right)^2.$$

Where O = Murgue's equivalent orifice,
V_0 = the volume in thousands of cubic feet per minute,
0·65 = the co-efficient for vena contracta taken by Murgue,
g = gravity, or 32·2 ft. per second per second,
h = the pressure in inches of water,
WG = water gauge in inches of water,
d_2 = mean weight of air,
d_3 = weight of a cubic foot of water.

In Murgue's formula it is assumed that the densities of air and water are respectively 1·2 and 1,000, or, in other words, water is 833 times heavier than air.

A perfect fan would produce a volume of air proportional to the equivalent orifice, and the curve would be a straight line. Owing to the inherent resistance of the fan the straight line is never obtained in practice, and a curved one takes its place.

Air Regulation.—At a colliery, regulation of the air delivered by the fan is essential; not only must the volume of air be varied according to the state of the weather, but at week-ends when no men are in the workings the volume of air may be economically reduced. This reduction is generally from 20 to 30 per cent. of the volume normally delivered.

The volume of air can be regulated in two ways—

(*a*) By altering the tip speed, *i.e.*, the revolutions of the fan;

(*b*) By throttling.

If the fan only and not the motive power had to be considered, the first-named method would be very efficient, as the power taken varies as the cube of the speed, with constant orifice.

As regards the second method, this is a wasteful process, as obstructing the air passage is equivalent to decreasing the equivalent orifice, so that although the air volume will be decreased in direct proportion, the WG will theoretically remain unaltered for a fixed tip speed of the fan; consequently, the power will only vary directly as the reduction in the volume.

Electrical Problem.—The chief problem which the electrical engineer has to solve is efficient speed regulation. With a continuous current motor this does not present any trouble. If the fan is driven by a shunt motor, the regulation can be effected by field control. In this case it must not be overlooked that the shunt motor will be working at its highest output with a weakened field; consequently the machine must be designed for these conditions, and will be much larger than a shunt motor for constant speed conditions.

As regards driving fans by three-phase motors, until recently there was a choice of only three ways to reduce the volume of air, viz.—

(1) By rheostatic control;

(2) By altering the number of poles of the motor;

(3) By cascade control.

(1) The first method has the advantage of being extremely simple and reliable, and as reliability is the prime consideration for a mining fan, this method deserves careful consideration On the other hand, it must not be forgotten that this is a very wasteful process, as the efficiency of the drive practically decreases directly as the decrease in speed.

(2) The second method is not to be recommended for general application, as it does not lend itself to the design of a high efficiency and high power-factor motor.

(3) If, however, instead of a resistance in the rotor circuit another motor is inserted in cascade, then the energy which is otherwise wasted in the rotor resistance can be re-converted into mechanical work. The stator of the second motor receives its energy from the rotor circuit of the first motor and the two rotors are rigidly coupled to the same shaft ; the speed of the set with the two motors coupled in cascade not only depends upon the number of poles in the first motor. but on the sum of the poles in the main and cascade motors.

To take a case in point : A four-pole machine will run at 750 r p.m. on a 25-cycle circuit ; if to this motor is connected in cascade a two-pole machine, the speed of the combination will be 500 r.p m., so that with the above arrangement it would be possible to run at full speed on ordinary weekdays and at two-thirds speed during week-ends. In some cases, however, the advantage gained by cascade control is more imaginary than real, as it must not be overlooked that the efficiency of the arrangement is the combined efficiencies of the two motors, and this, especially when the motors are small and working at reduced output, may result in a very small gain.

As stated generally above, speed regulation by resistance in the rotor is wasteful. This mainly applies to cases where constant torque or increased torque is required at reduced speeds. However, in the case of a fan, as we have seen the power for driving varies approximately as the cube of the speed. Take the case of a fan requiring 125 h.p. on full load at 255 r.p.m. ; reducing this speed to half, or 127½ r.p.m., will theoretically bring down the power absorbed to 15·6 h.p. But reducing the fan speed 50 per cent. does not waste 50 per cent. of the full input of the motor, as only 50 per cent. of the

energy of the motor is actually taken from the supply at the moment, or, say, $12\frac{1}{2}$ per cent. of the full load input.

Cascade Control.—The author was responsible for putting

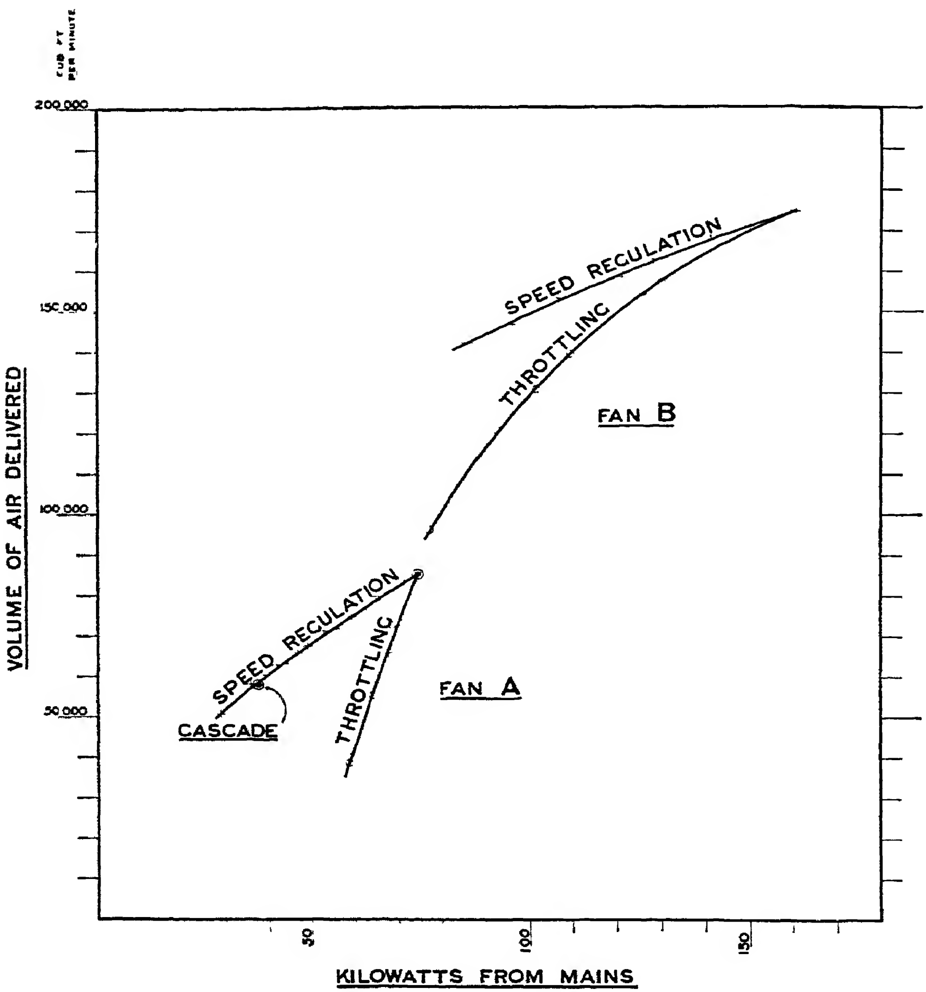


Fig. 111.—Regulation of fans.

down an ordinary cascade system for driving a double inlet steel plate Schiele fan, 10 ft. in diameter, with self-aligning bearings and ring oil lubrication, capable of exhausting 100,000 cub. ft. of air per minute at 4 in. WG when running at

255 r.p.m. It was driven by cotton ropes from a 125 h p. three-phase 25-cycle motor. The motor was arranged on the cascade system, the main motor having four poles, the small motor two poles with suitable switches to give alternative speeds of 485 and 720 r.p.m.

This arrangement was adopted, as regulating by a resistance in the circuit of the motor was considered and turned down, the consensus of opinion appearing to be against it on account of its reputed inefficiency.

Rheostatic Control *v.* Throttling.—After the above fan was put to work some eight years ago the author further considered the question of regulation and made some experiments upon this fan.

When a fan speed is varied the power varies approximately as the cube of the speed ; hence when a motor is driving a fan and its speed is reduced by the insertion of resistance in the rotor circuit, the torque, due to the resistance, is greater than that called for to drive the fan at the reduced speed . the result is a compromise of a new speed with a lower torque and reduced current.

Fig. 111 shows in curve A the result of regulating the Schiele fan by throttling in the air drift and by the insertion of resistance in the rotor circuit respectively. The effect of the change of speed due to the cascade is also indicated.

The cascade arrangement gave no choice of steps between full speed and slow speed, while with the regulating resistance several intermediate speeds could be obtained.

A comparison of the throttling curve and the speed regulation curve shows that the same volume of air may be delivered by each, but at a considerably decreased input in the case of the speed regulation by resistance.

The above trials, which were only made with temporary resistance gear, appeared to be so promising that arrangements were made to apply the system to other fans. Two further fans were required to be put down in place of old steam-driven Waddle fans, which were about 45 ft. in diameter with 16 ft. inlets, having a duty of 120,000 cub. ft. per minute at 2 in. WG. It was arranged to put down duplicate

fans, rope driven, and of a larger ultimate duty than was initially required.

The duties called for were :—

	Ultimate.		*Initial.*	
	cub. ft	WG.	cub. ft.	WG.
(1)	125,000 at	4·3 in.	111,500 at	3·5 in
(2)	150,000 at	3·5 in.	131,500 at	2·75 in.

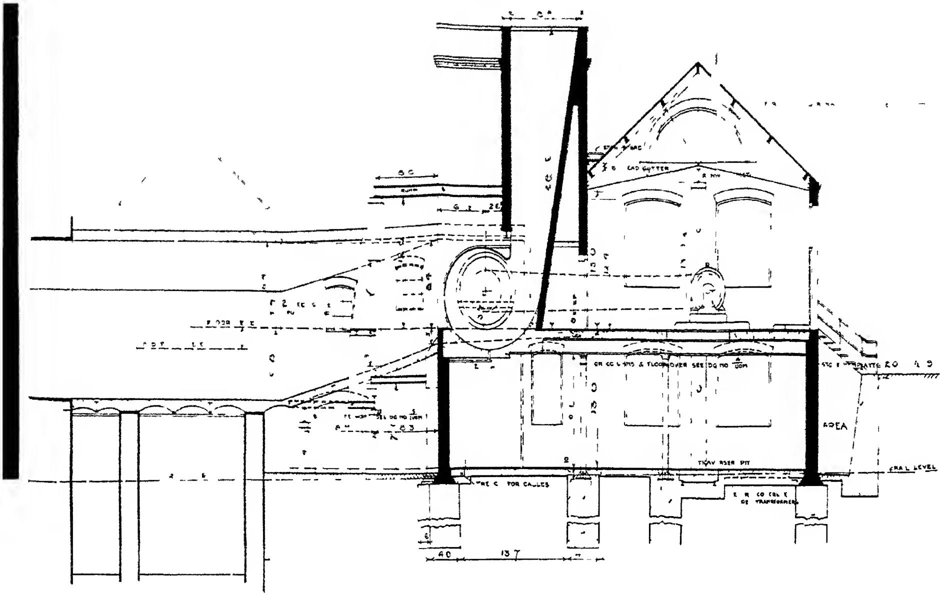
For the sake of uniformity and duplicate parts a little sacrifice was made in efficiency and duplicate plants put down in each case, the only difference being the speed at which the fans were run.

Fig. 112 shows the general arrangement of one of the fan houses, the ground floor of which was used as a transformer sub-station.

Sirocco Fan.—The fans chosen are of Messrs. Davidson's "Sirocco" type, 77 in. in diameter, with double inlets 77 in. diameter. They are driven from either end of the shaft by means of nine $1\frac{3}{4}$ in. cotton ropes. Clutch couplings are provided on each side of the fan so that the rope drive at either end can be disconnected. Metallic resistances are used for regulating the speed and are designed to allow a continuous speed reduction of 30 per cent.

The special feature of the "Sirocco" fan is the short blades, which are concave to the direction of rotation and the large inlet. The fans are of small diameter and high speed, and so lend themselves readily to direct coupling to electric motors. Rope driving was adopted because the fans were put in for much larger capacity than would be required for some years to come. This condition was readily and cheaply met by putting a smaller pulley on the motor, which can be changed for the larger pulley calculated to drive the fan at full speed at a later date.

Before No. 2 fan was put on to its permanent duty the opportunity was taken to test it under fresh-air conditions on a temporary drift with an adjustable orifice, and to determine the losses in the rope drive. The motor running light without ropes absorbed 5 k.w. ; the motor, driving ropes and the short length of shaft carrying the pulley 15·5 k.w. The difference



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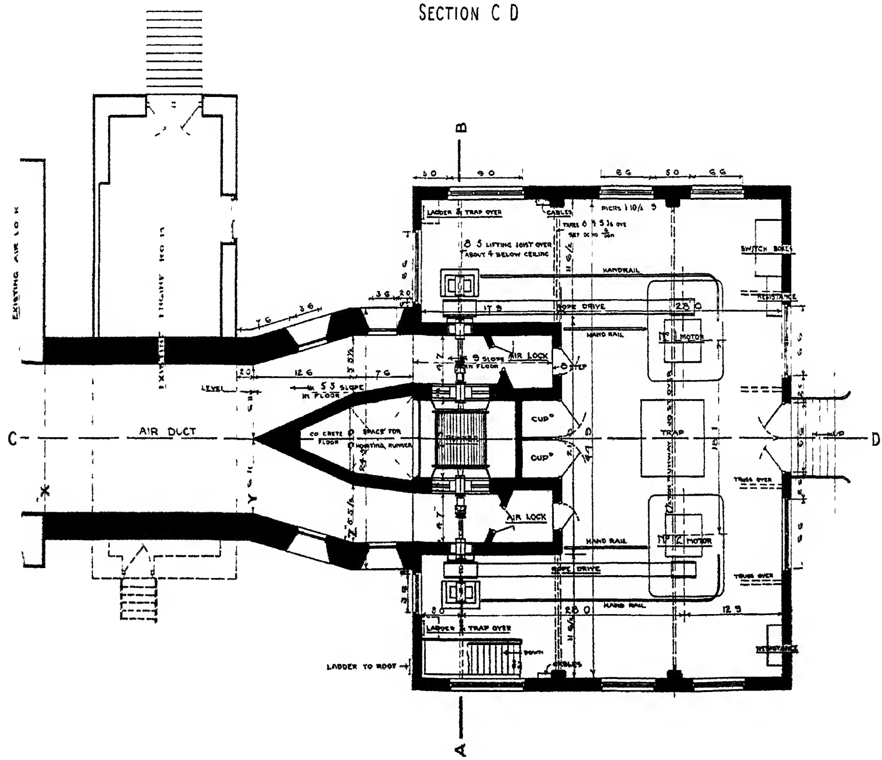


FIRST FLOOR PLAN

To face page 198.

FIG H2.—Middle fan-houses, Ferndale. Plan and section

between these figures is 10 5 k.w = 14 1 h.p., and represents the power absorbed in the rope drive, including the friction of the two shaft bearings and the friction and windage of the ropes; 14·1 h.p. = 7·9 per cent. of the full output of the motor, so that the friction of the rope drive may be taken as 8 per cent.

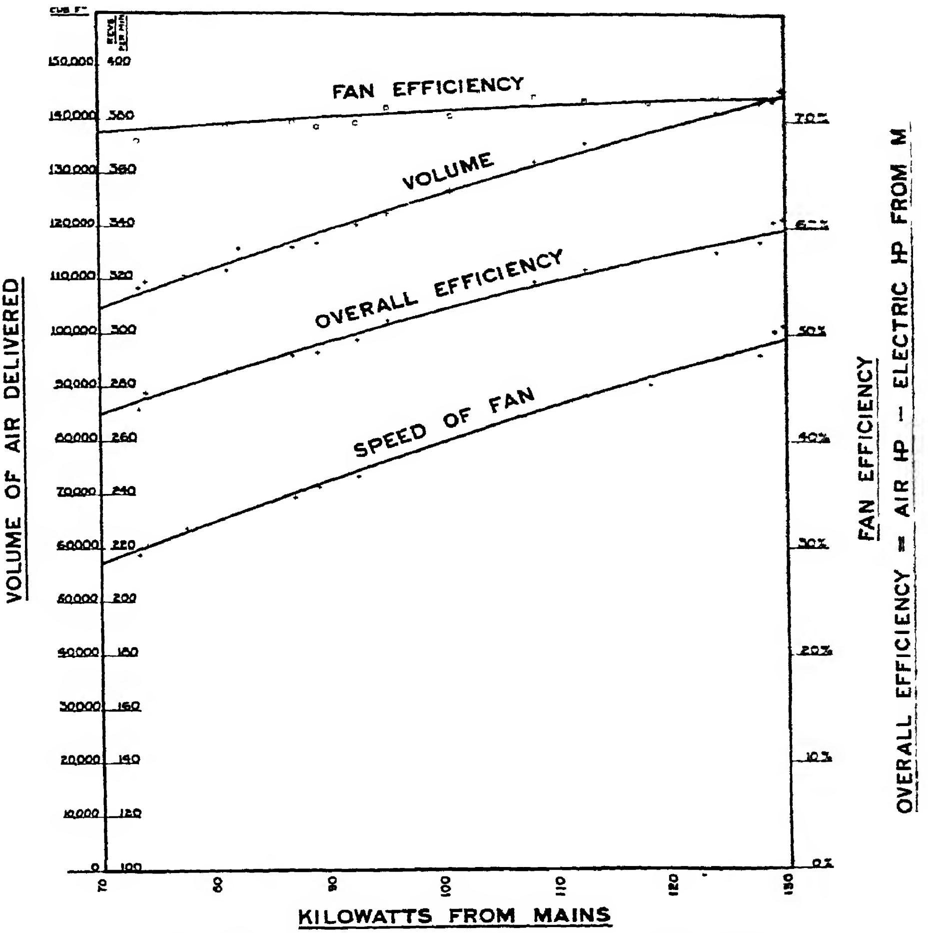


FIG. H3.—"Sirocco" fan test, Ferndale. Efficiencies.

of the full load, on the assumption that the friction in the rope drive is constant for the same speed.

Curve B on Fig. H1 compares the result of throttling and speed regulation in the case of the Sirocco fan, which was driven off a temporary small pulley until the maximum amount of

air is required. The saving shown by the speed-regulating arrangement is very great as compared with what can be obtainable for the same electrical input under throttling conditions. The relative shape of the A and B curves must not be taken as indicating the comparative value of the two fans, as they are

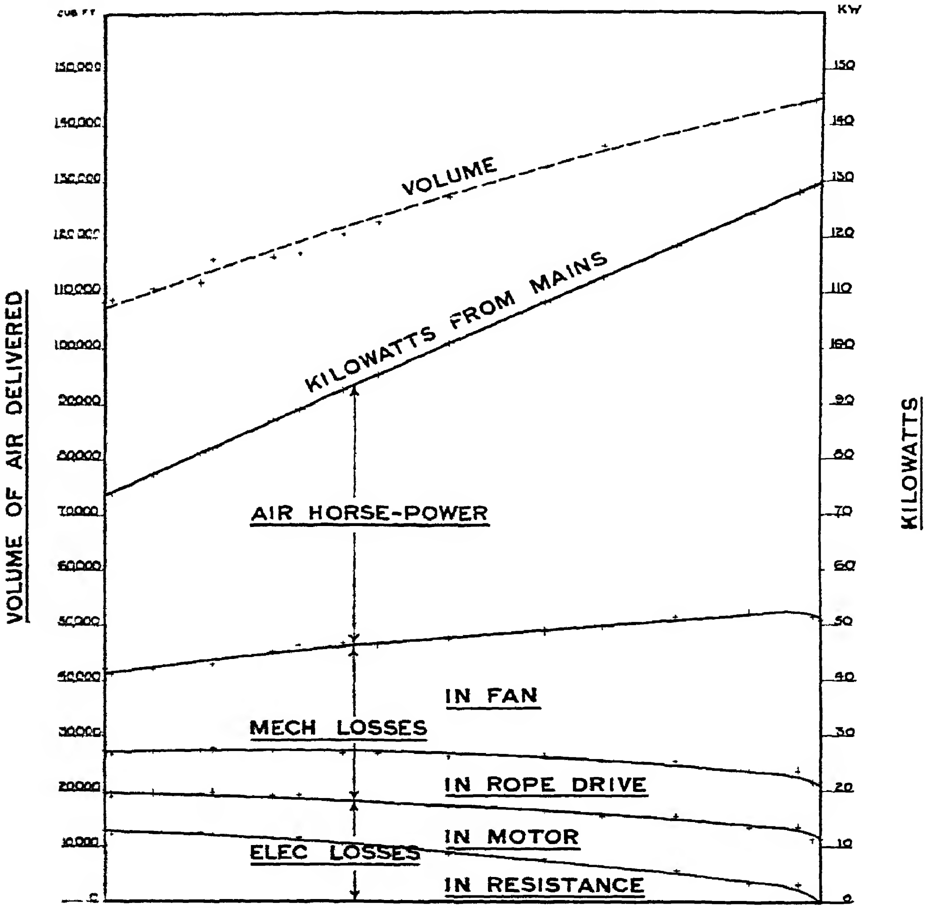


FIG. H4.—" Sirocco " fan test, Ferndale. Losses analysis.

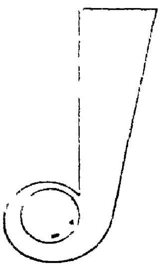
not designed for the same load, nor are they running under the same conditions. The curves are only shown to prove that for fan-driving speed regulation by a resistance is an economical and convenient method.

Several tests were made on these fans, and in working out

the results it was assumed that the friction in the rope drive varied directly as the speed.

The air volumes were measured with an anemometer on the top of the chimney, which was divided into squares by fine wires, the electrical readings being taken on two carefully calibrated watt-meters.

Figs. H3, H4, show two sets of these readings. Fig. H3 shows the speed of the fan, the overall efficiency, the volume of air delivered, and the fan efficiency. Fig. H4 shows the



DIRECTION OF ROTATION

1984	1731	1673	2029	2432	2675
1789	1389	1406	1610	1744	2325
1771	1733	1568	1406	1578	2245
1690	1859	1554	1568	2263	2110

AVERAGE VELOCITY = 1839 FT PER MINUTE

FIG H5.—Distribution of air over top of fan chimney

analysis of the efficiency, or rather of the inefficiency, as it was calculated to show where the various losses occurred and to what extent they were electrical or mechanical.

A further determination was made by measuring the velocity of the air entering the orifice, while the volume was also measured on the chimney top. The vena contracta of the orifice, which was formed in timber of about 2 in. thickness, was found to be in the neighbourhood of 0·80.

Fig. H5 shows how the velocity varied in the twenty squares into which the chimney was divided. The point is interesting,

and does not appear to have been published previous to the author's drawing attention to it (Proc. S. Wales Inst. Eng., Vol. XXVI., p. 890), when his figures were scouted as incorrect and impossible. Further investigation, however, proved that the effect had been observed, although it had not been published. The author's attention was first drawn to it by the behaviour of wooden shavings or chips which he threw into the chimney, and which played about in the current as if alive, sometimes travelling fast up the side, then getting into an eddy, turning over towards the middle, and then dropping, till, when caught in another air current, they were once more projected upwards.

Under certain conditions the effect may be exaggerated to such an extent that an actual down draught in the centre of a chimney may be measured, and readings 50 per cent. and even 150 per cent. higher at the side than in the centre have been noted.

Walker Fan.—Another instance of rheostatic speed control of a different type of fan may be mentioned, where the pit was fully developed and the maximum capacity could be utilised from the start. The duty specified was 400,000 cub. ft. of air per minute at 5·5 in. WG, for which one of Messrs. Walker Brothers "Indestructible" fans was chosen. The lay-out included two 700 h.p. motors direct coupled, one on each side of the fan, through claw clutches. The fan is 18 ft. diameter by 7 ft. 6 in. wide, and with double inlets 11 ft. diameter. The motors are provided with speed-regulation resistance of the metallic type, sufficient to reduce the speed 25 per cent. with twenty-seven intermediate steps. The upcast shaft upon which the fan works is also used for a winding shaft.

As the shaft is a winding shaft without any system of air locks, one half of the shaft cover has to be lifted each time that a cage is banked, and sometimes when it is necessary to lower material down the shaft the cage has to be lifted considerably above the ground level, when fresh air can run in from the surface and short-circuit the resistance of the mine. While the old steam-driven fan was in use the effect of the cage being above the surface was only noticed by the engine slowing up,

but when a fan is driven by a three-phase motor the motor will try to keep up full speed, and the large volume of air which can then be handled may overload the motor. The tests recorded in the three columns in Table H1 were taken with a view of getting information upon this point.

TABLE H1.

Position of Cages.	Column 1	Column 2	Column 3
	Both Covers Down.	One Cage [illegible] above Keps	One Cage 6 ft above Keps
Input, k w. ..	466	540·8	608
Input, e h.p.	624	725	815
Motor efficiency (per cent)	93·3	92·7	92 3
B.h.p. fan shaft	582	672	752
Revs. per min.	183	183	181
Vols of air (c ft. per min.)	388,800	466,500	524,400
Water gauge (inches)	6 8	6·1	5 25
Air h.p.	416 6	448 4	433 8
Overall efficiency	66 7	61 9	53 2
Fan efficiency	71 7	66 8	57·7

Air Vibration.—A special feature in the Walker fan construction is the anti-vibration shutter, which is designed to prevent the vibration set up in the air and blades of the fan when its various compartments are suddenly changed from atmospheric pressure to the full water gauge at which the fan is working.

The introduction of this anti-vibration shutter is very important for slow speed fans, and followed the adoption of three Guibal fans made by Messrs. Walker in about the year 1886 for the Metropolitan and District Underground Railway. The vibration caused by these fans was so unpleasant that an injunction against the railway company compelling it to stop one of the fans was obtained. When the makers heard of it, it occurred to them to incline the lower edge of the shutter instead of making it parallel with the axis of the fan, but it was ultimately decided to make the shutter like an inverted V, and this was found completely successful. The breakage of the fan shafts, and the loosening of bolts and rivets in fans generally, may be attributed to the excessive vibration which before the introduction of this improvement was inseparable

from their working. The vibration is caused by the too abrupt passage of the fan blades from the chimney opening to the shutter, which previously had a line parallel to the tips of the fan blades. When the fan is running the pressure is against the front of the blades, but immediately the blade enters the fan casing the load upon it is suddenly removed, and the pressure, owing to the vacuum within the casing, is instantaneously reversed, and a rebound upwards of the previously depressed blade takes place.

In a description of the Walker fan (Trans. Manchester Geological Society, part 15, Vol. XXII.) a case is quoted in which experiments were made upon a Guibal fan. "Readings were taken from a water gauge which was attached to the fan casing at intervals from the centre to the periphery above the fan shaft. At the centre the water gauge indicated 3 in., but near the outer edge or periphery it was half an inch. The fan was 24 ft. in diameter and ran at 80 r.p.m. Taking the average water gauge over the surface of the blades as $1\frac{1}{2}$ in., it would represent a pressure of 7·8 lbs. per square foot, or a total pressure on each blade of nearly 500 lbs. Assuming the centre of the blade to be the centre of the load, the distance from the centre of the load to the centre of the fan shaft would be approximately 9 ft. Taking the work of one day of 24 hours, the fan running at 80 r.p.m.—8 blades $\times$ 80 revs. $\times$ 60 mins. $\times$ 24 hrs. $=$ 921,600. This product represents the number of times in a single day that a weight of at least 500 lbs. is, as it were, instantaneously removed from the blades, and the shock resulting from the removal is transmitted to the fan shaft. The shaft is thus in a constant state of tremor, and sooner or later reaches its elastic limit. The consequent injury to the general structure of the fan is obvious." Messrs. Walker's invention completely gets over this trouble by effecting a perfectly gradual change in the pressure on the fan blades.

Sandycroft Cascade Induction Motor.—An important improvement in tandem motor control has been effected by Mr. Hunt, of the Sandycroft Foundry Co. In the simplest form the motor is provided with a short-circuited rotor winding without slip-rings, and has the same characteristics as an ordinary slip-ring

motor. The starting or regulating resistances are connected to tappings in the stator winding, and the speed can be varied from zero to full speed by adjusting the resistances. A development of this type is that in which the rotor has a double winding and is provided with three slip-rings. It runs at two efficient speeds without losses in resistance, the intermediate steps being obtained by rheostatic regulation. At starting it will develop the full-load torque taking only 0·7 times full-load current ; or it will start against twice full-load torque taking only 1·4 times full-load current. When taking a starting current equal to the full-load current it will develop about 1·45 times full-load torque. Therefore it will be understood that the losses in resistance when starting or running at speeds below synchronism are far lower than those of a slip-ring motor of ordinary design.

For example, a motor with a rotor wound for 20 and 10 poles will give fixed speeds corresponding to 10, 20 and 30 poles, or speeds corresponding to full-load speeds of 100, 50, and $33\frac{1}{3}$ per cent. If the motor is wound for 20 and 30 poles, we shall get full-load speeds corresponding to 100, 66·6 and 40 per cent.

Take the case of a two-speed machine to be adapted for fan driving. If the colliery management require a reduction in air of one-third during the week-ends when the pits are idle, all that has to be done is merely to throw over the switch on the tandem contact, and the motor runs without any rheostatic losses. If, however, the management specify a volume of air of 80 per cent. during week-ends, *i.e.*, a speed reduction of 20 per cent., the tandem motor in this case will not be more advantageous than the ordinary three-phase motor, as the 20 per cent. speed regulation is above the tandem speed and only obtainable by inserting a resistance in the rotor.

In cases where during the initial stages of development a reduced volume of air is required, the cascade motor offers great advantages, as the motor can be run at one-third or half speed, according to requirements, thus obviating the losses in gearing or rope drive and the changing over of the latter when the machine has to develop its full volume.

The curves (Fig. H6) show the performance of a 300 h.p.

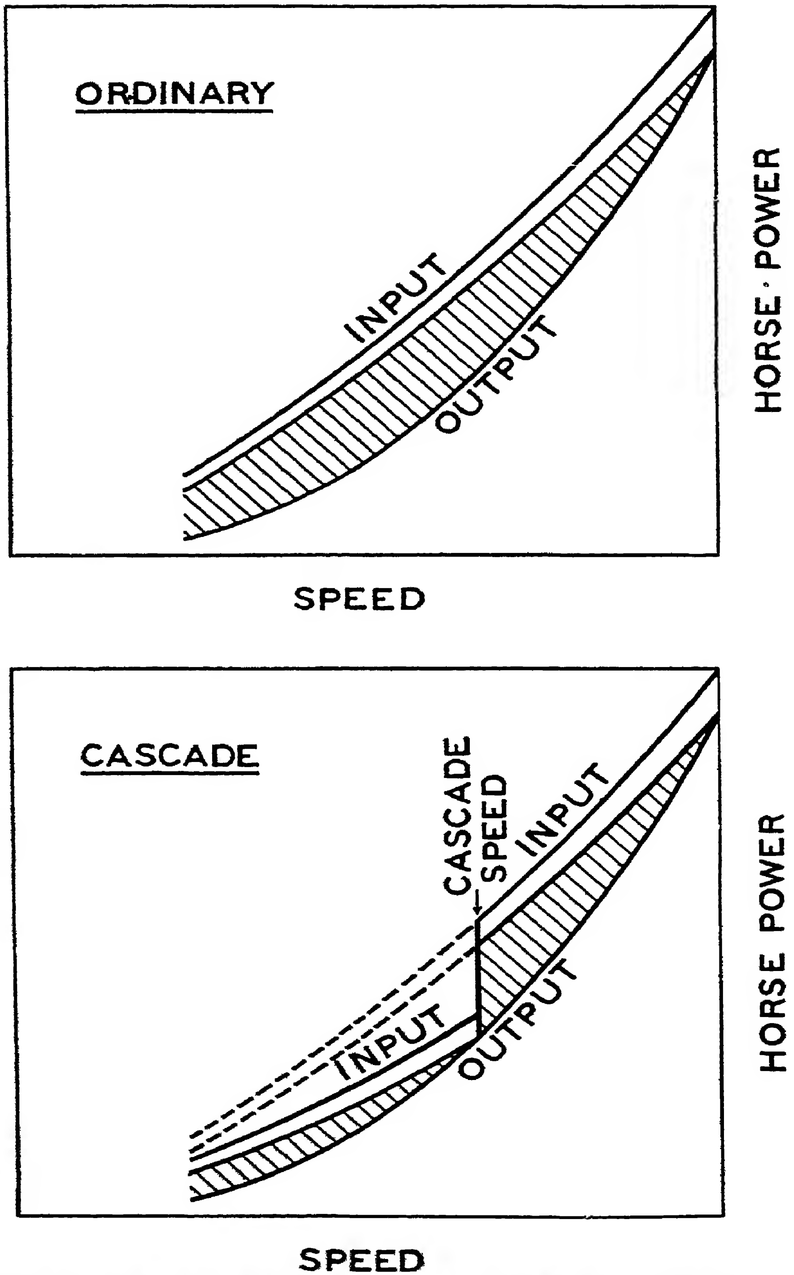


FIG. H6.—Losses in regulation with Sandycroft-Hunt cascade motor, compared with an ordinary slip-ring motor.

motor, with full speed of 365 r.p.m., regulated by a resistance in the rotor contrasted with the performance of a Sandycroft Cascade motor arranged for two fixed speeds, the cascade speed being two-thirds of the full speed. The curve representing motor output has been drawn on the assumption that the power required by the fan varies as 2·5th power of the speed.

As will be seen from the curve, from full speed to two-thirds speed the loss is the same, whether an ordinary slip-ring motor or a cascade motor is used. At this point, however, the cascade switch is closed, and the cascade motor now again runs without any resistance in the rotor, hence there is no rheostatic loss. It is starting from this point that the great advantage of the cascade motor becomes apparent. Any further speed regulation of the Sandycroft motor can be effected by the resistance in the stator tappings, and it will be seen that in the case of the cascade motor the rheostatic losses are now proportional to the cascade speed, and not to the full speed, as is the case for the ordinary slip-ring motor. (See also page 161, *ante*.)

Regulation by Commutator Motors.—Within the last few years much attention has been paid to the problem of producing a suitable three-phase commutator motor giving perfect speed regulation. Unfortunately, these efforts have not yet met with complete success, although several types are now on the market, amongst which that patented by M. Latour is one of the most successful. For large powers and high frequencies the use of these motors is restricted on account of commutation troubles.

Mr. C. Kramer, formerly of the Lahmeyer Co., patented an arrangement whereby a polyphase commutator motor is switched in cascade with the main motor, so that the slip energy of the rotor of the main motor is used to feed the commutator motor, which latter returns it as mechanical energy to the shaft. Sometimes the commutator motor is directly coupled to the main motor shaft, or its place may be taken by a rotary converter, this supplies energy to a continuous current motor which is directly coupled to the main motor; in each case the slip energy which would otherwise be lost is

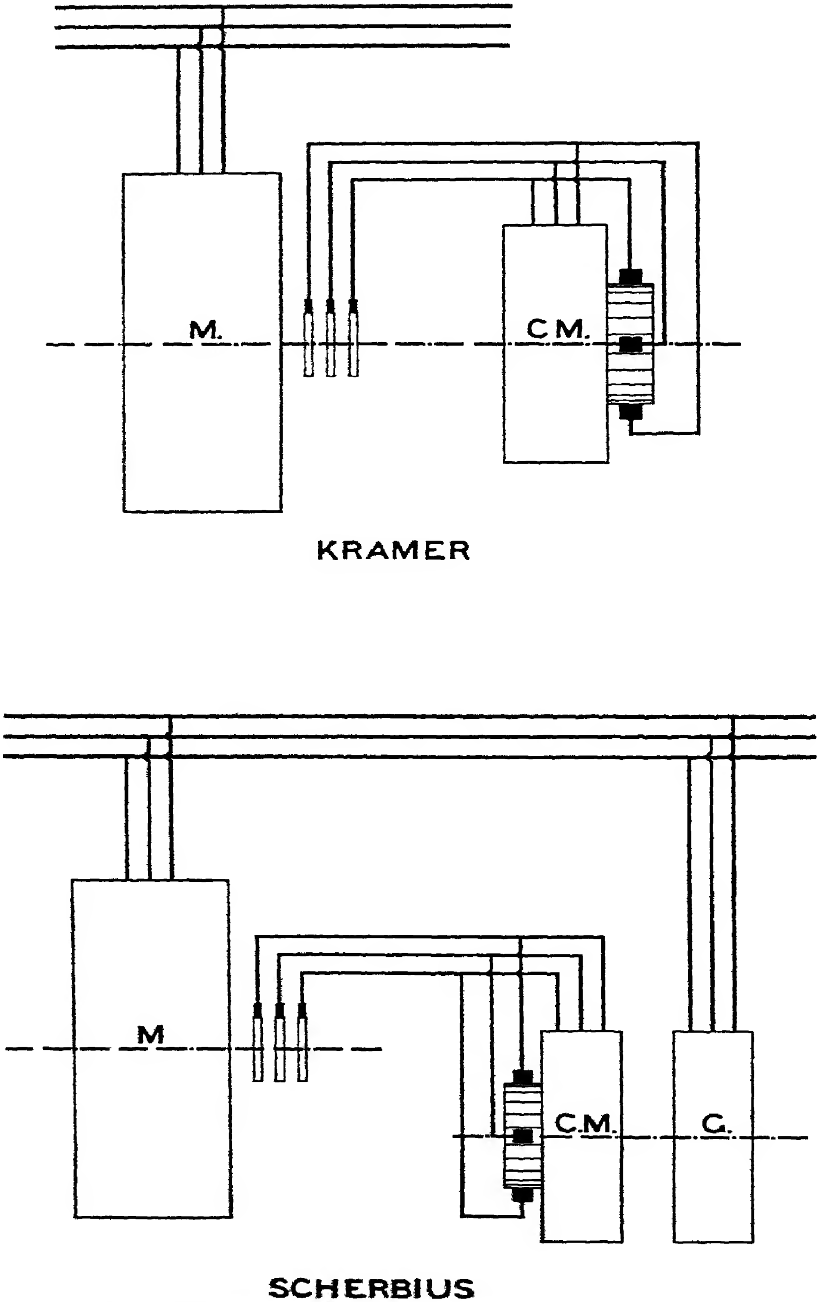


FIG. 117.—Connections of Krämer and Scherbius systems.

converted into mechanical energy and used on the main motor shaft.

Another arrangement is due to Dr. Scherbius, who takes the slip energy to a commutator motor coupled direct to a three-phase generator, and so returns the energy to the line electrically instead of mechanically as in the Kramer system.

The advantages of these two systems will be readily appreciated, as

First, a gradual speed regulation is procured with a very small loss of efficiency, and any required relation between speed and load is possible, as in the case of a C.C. machine.

Second, the arrangement allows of power-factor correction, making a smaller induction motor possible.

Third, if the commutator motor be wound for a series or a shunt characteristic the main motor will operate with a similar characteristic.

In the case of the **Krämer System** of speed regulation the auxiliary motor will have an output corresponding to the percentage regulation required—that is to say, for 30 per cent. speed regulation the auxiliary motor must have an output of 30 per cent. of the output of the main motor. Fig. H7 gives the connections of the Kramer system where the commutator motor is on the same shaft as the main motor. The motor can be started up in the usual way by resistance in the rotor; this resistance is short-circuited as soon as full speed has been attained, and regulation is then effected by tappings in the field circuit of the commutator motor.

If the Kramer system be applied to the case worked out on p. 206 for a 300 h.p. motor, it will be seen that for 30 per cent. speed regulation, or a speed of 255 r.p.m., the fan would take 123 b.h.p.; allowing an efficiency of 80 per cent. for the commutator motor, it is found that a further 6 per cent. would be lost in the motor, which compares very favourably with the 30 per cent. lost in resistance when working with rheostatic control.

The Scherbius System, the connections of which are shown in Fig. H7, is suitable when it is impossible to put an auxiliary motor on the main shaft. As there is one more conversion in

the Scherbius system than in the direct-coupled Kramer system, the efficiency is slightly below that of the latter.

The Scherbius motor, like the Kramer motor, has the characteristic of a continuous current machine, and impresses this characteristic on the main motor, so that for fan driving a shunt wound commutator motor would be required.

An electric fan with the Scherbius speed regulation is at work in the Rheinelbe I. and II. Pits at the Gelsenkirchen Collieries. The maximum output of the plant will not be required for a number of years; consequently some method of speed regulation was advisable, and the Scherbius system by Messrs. Brown, Boveri & Co. was that selected. The induction motor has an output of 1,000 h.p. maximum on continuous rating, and is connected to a 5,000 volt, 50 cycle supply. The full speed is 363 r.p m., and regulation was provided to 26 per cent. decrease. The Brown, Boveri-Scherbius regulating set consists of a 200 k.v.a., three-phase commutator motor coupled to an asynchronous generator of 85 k.w. at 750 r.p.m. Arrangements are made by which the rotor of the main motor is connected in mesh for low speeds and in star when the speed exceeds a certain value. This enables the cascade motor to be reduced to about 58 per cent. of the size that it would have to be without the change from mesh to star.

The method of starting and regulating the plant is quite simple. The generator of the Scherbius set is first of all started from the line, as an induction motor, in the ordinary way with a resistance in its rotor. Then the main motor is started up with a resistance in its rotor, after which the slip-rings are connected to the motor of the regulating set by means of a change-over switch, which is operated automatically, so that the attendant has only to manipulate the two rotor rheostats in succession; the change-over having been automatically made, all that remains to be done is to set the speed of the main motor, which, as previously mentioned, when coupled to such a regulating set, has a speed characteristic similar to that of a shunt-wound continuous current machine, by means of a regulating transformer. The transformer is provided with a 20-contact hand-operated regulator, each step of which corresponds to a certain excitation of the commutator

motor, and a definite speed of the main motor, which may be regulated for any speed between 268 and 363 r.p.m. by twenty equal steps.

The results of tests carried out on the plant for full speed and reduced speed are given in Table 112.

TABLE 112

R P M	Input E H P	B H P.	Volume c. ft per Minute	WG	Air H P	Efficiency Overall	Efficiency Fan
360	1,043	970	290,000	18·5	845	81·0	87·0
268	450	370	194,500	10·0	306	68·2	82·5

The energy in kilowatts, with a speed of 268 r.p.m., controlled by the regulating set is 335, as compared with 412 k.w., which would be called for with resistance control, and as the fan runs all the year round, if the energy is charged at ½*d.* per k.w. hour the annual saving is £1,405.

Two installations on these systems are working at the Wendel Pit at Hamm, and the Deutsche Kaiser Pit at Hamborn. It will be realised that, although for fans of moderate size the direct rheostatic control is the most reliable, and, as shown, the energy wasted in the resistance does not amount to a great deal, when, however, the fan is large the slip energy wasted in the resistance becomes a considerable item.

At the International Congress at Dusseldorf, 1910, Chief Engineer W. Phillippi cited a case of a 1,000 h p. fan with a speed regulation of 20 per cent. working over 8,760 hours a year. Mr. Phillippi found that by controlling the speed of this fan by means of a regulating motor approximately 700,000 k.w. hours were saved, as compared with rheostatic control. This at 0·416*d.* per k.w. hour means a saving of £700 per annum ; hence the extra cost involved in buying the regulating motor and rotary converter would be covered in a few years.

There are other types of fans all of which may be driven electrically. Restrictions of time and space prevent their being dealt with here. The Waddle, the Schiele, and the Guibal types were exhaustively tested by a Committee, and reported on by the late Mr. Walton Brown in what is one of the most complete investigations of mining fans that has been carried

out (Trans. Inst. Min. Eng., Vol. XVIII, p. 482). The Mining Institution would do good service if they inaugurated a similar research and brought the work up to date, as considerable progress has been made in the twenty-three years which have elapsed since the above tests were completed.

Of the modern types the Barclay, the Bumstead-Chandler, the Capell, the Heenan-Froude, the Rateau, the Sirocco, and the Walker may be mentioned without exhausting the list.

The introduction of the "Sirocco" type seems to have influenced the construction of other fans, as blades in most modern fans are shorter and the inlets are of larger diameter than in the older models. The tendency to reduce the diameter and increase the speed of fans is possibly as much due to electrical driving as to the influence of any particular maker.

No fans are now being built of a diameter approaching that of the early Waddle, which frequently were built upwards of 30 ft. in diameter. Some managers who have handled fans of large diameter are much averse to the small diameters and high speeds. If they can find space and the necessary capital there is no reason why they should not put in large diameters, although the modern type of a medium diameter fan can give a better commercial efficiency.

Table H3 gives the leading particulars of tests of some Electric Mine Fans of different types, ranging from about 100 to 1,000 h.p., which may be interesting, as supplementing the figures of other fans given above. The fans are arranged in order of the horse-power in the air delivered.

The largest fan on the list is provided with a resistance regulation. Most careful tests were taken on this fan under throttling and resistance regulation conditions respectively with a speed of 228 r.p.m. and 206 r.p.m. The energy consumption per 1,000 cubic metres volume of air regulated by means of throttling with the motor running at full speed was 63·8 k.w., as compared with 56·5 k.w. at 206 r.p.m. of the motor obtained by means of resistance regulation, the quantity of air in each case being approximately the same. This shows a saving of 11½ per cent. in favour of resistance regulation.

TABLE H3.—TESTS OF ELECTRICALLY-DRIVEN FANS.

Maker and Type of Fan.	Davidson & Co., "Sirocco"	Davidson & Co., "Sirocco"	Davidson & Co., "Sirocco"	Davidson & Co., "Sirocco"	Walker Bros., "Indestructible"	Walker Bros., "Indestructible"	Walker Bros., "Indestructible."	Capell Fan Co	Walker Bros., "Indestructible"	Davidson & Co., "Sirocco"	Capell Fan Co	Schuchtermann & Kramer, "Rateau."
Locality	Yorkshire	Durham	Yorkshire.	Lancashire	Lancashire	Fifeshire.	Midlands	Northumberland	Northumberland.	South Wales.	Sunderland	Westphalia.
Date of Test	Apr '08	Apr '08	Dec '08	Nov '11	June, '10	—	Mar '09	—	—	Feb '09	Sep '11	Jan '10
Diameter of Fan	9' 4"	5' 10"	8' 0"	14' 7"	16' 0"	18' 0"	20' 0"	13' 6"	—	11' 8"	14' 6"	14' 0"
Width of Fan	6' 8"	4' 7"	6' 4"	5' 7½"	6' 0"	7' 0"	7' 0"	4' 0"	—	5' 8"	5' 10"	—
Revolutions per Minute of Fan	140	338	169	80½	169	145	126	223	—	183	200	226
Drive	Direct	Direct	Ropes	Ropes	Ropes	Ropes	Ropes	Ropes	Ropes	Direct	Ropes	Direct
Water Gauge (inches)	1.8	1.0	2.5	2.12	4.28	3.8	4.3	6.85	5.0	6.0	6.3	13.14
Volume of Air (cubic feet per minute)	208,000	133,100	220,320	287,920	215,000	302,890	320,130	212,460	312,630	340,000	310,000	372,800
Horse power in Air	58.9	84	88	96	165.2	181	217	229.5	246	321.5	337.5	773
Electrical Input (Horse-power)	88.4	139.4	134	153.8	240	262	312.4	—	332	420	—	960
Efficiency Overall (per cent.)	66.6	60.3	65.7	62.5	69	69	69.5	—	71	76.6	—	80.5
" of Fan "	75.4	—	—	73.9	79	80	82.5	82*	86.6	82.4	79.6*	86.5
" of Motor "	88.1	—	—	92.5	92	90	88.4	—	90	93	—	93
" of Ropes "	—	—	—	91.5	95	96	95.4	—	95	—	—	—

* Including losses in rope drive.

Air Compressors.—A compressor plant and transmission system is of great utility, but the character of the equipment is often such that its low efficiency greatly interferes with its utility. Theoretically air compressors have high mechanical and volumetric efficiency, and pipe lines can be designed of such size that the loss of pressure is very small ; but unfortunately all compressors are not efficiently operated, and as large pipes are awkward things to handle and accommodate in a mine, the efficiency of the system suffers accordingly.

In the Journal of the S. African Assoc. Eng., Vol IV., 1897–8, Messrs. Hulton and Schweder established the figure of 28 i.h p. in the steam cylinder of the compressor as necessary to keep a $3\frac{1}{4}$-in. drill, which requires 5 to 6 h.p., running. Other investigators have found 25 h.p. at the compressor necessary per 5 h.p. drill ; hence the efficiency is about 25 per cent. Where coal cutters are used 60 lbs. pressure at the bank has often been found to give only 20 to 30 lbs. at the coal cutter. Part of the loss is friction and part due to leakage of air from faulty joints and drain cocks, but there is no valid reason why the conditions should not be considerably improved.

In some cases the compressors may be large units working on the surface, in other cases small units in-bye may be more convenient.

The claim that the use of compressed air improves the ventilation of the working places is more imaginary than real, and the quality of such air may be better worth consideration than the quantity. Many cases of poisoning by compressed air contaminated by the products of combustion of the lubricating oil and dust in the compressor cylinders have occurred ; explosions due to this cause have been frequent, and flaming in some places is a common experience. It is, therefore, necessary, particularly in the case of in-bye compressors, to use high flash-point lubricating oil in the cylinders and very little of it, to filter the air, and to make sure that the design of the compressor is such that it can be readily cleaned out.

In connection with rock-drilling and coal-cutting machines compressed air was mentioned as necessary when the conditions do not permit the introduction of electricity into the workings. The large slow-speed steam-driven compressor now has to

meet a high-speed steam-driven rival, and it is a very short step from driving such a compressor by steam to direct coupling it to an electric motor.

A compressor is a constant torque machine, that is, the torque is constant at all speeds, the horse-power varying within wide limits directly as the speed. The difficulty which confronted the adoption of electric driving was speed regulation. As we have seen, this offers no obstacle with continuous current motors, but with the ordinary three-phase the drive is very inefficient, as the input to the motor driving the compressor is constant, irrespective of the speed at which it runs.

The disadvantages of stopping and starting the motor are obvious, so some other means must be found by which the power taken by the motor is reduced when the full air supply is not called for. Various systems of effecting this have been arranged. The principal are :—

(1) Throttling the air at the inlet valve, so that on one stroke a partial vacuum is formed and on the return stroke the work in forming it is partly returned to the engine ;
(2) Unloading the delivery side and allowing the air to be discharged to atmosphere without compression

When the pressure exceeds the maximum requirements the unloader either closes the inlet, allowing the compressor to run practically without load at full speed, and when the pressure falls to within 3 or 4 lbs. below the maximum the unloader reopens and the motor takes up the load again immediately ; or the unloader may be arranged to relieve the pressure on the delivery side, in which case a check-valve is fitted between the compressor and the receiver ; the latter method is generally preferred.

The Ingersoll Rand Co. make a special magnetic unloader, but in connection with their highest class compressors they rely upon their automatic clearance controller, which is a purely mechanical device for varying the amount of clearance in the compressor. It consists of a number of clearance pockets, which are thrown automatically into communication with the ends of each air cylinder in proper succession, the process being controlled by a pre-determined variation in receiver pressure. When the compressor is operating at partial

capacity a portion of the air is compressed into an added clearance space instead of passing through the discharge valves. On the return stroke this air expands, giving up its stored energy to the piston. The inlet valves remain closed until the cylinder pressure equals the intake pressure. The inlet valves then open automatically by a slight difference of pressure, and free air is admitted to the cylinder for the remainder of the stroke. On a two-stage compressor clearance space in the proper proportion is added simultaneously to both cylinders. The reduction in power secured with this method of control is practically in direct proportion to the reduction of load, the machine friction, of course, remaining constant.

Some large compressors are running in South Africa, where the governing is effected by allowing air from the delivery to return to the cylinders during the suction stroke. Four machines, each capable of compressing 5,000 cub. ft. of free air per minute to a pressure of 80 lbs. per square inch, with a mechanical efficiency of 90 per cent. and requiring 800 h.p. at 107 r.p.m., have been working for some time at the Randfontein Central Mines (T. P. E. Butt's Paper, Journal S. African Inst. Eng., June, 1911). The first two have synchronous motors with an auxiliary starting motor; the other two are provided with induction motors. The operation of the synchronous motor sets has been so satisfactory that a similar set has since been ordered for an adjoining mine. The motors are wound for 2,000 volts and are mounted on the shaft between the cylinders of the horizontal, two-stage compressor. The starting motors on the synchronous sets are 100 h.p., geared to the main shaft by striking gear and capable of carrying 100 per cent. overload for short periods.

One great advantage of driving air compressors electrically by synchronous motors is that it offers a ready means of power-factor correction.

The starting gear is simple, and presents no greater difficulties than that for an induction motor, the only disadvantage being the necessity of a continuous current supply for excitation. This may be met by mounting the exciter on the compressor bed-plate and driving it from the crank shaft.

The Anaconda Copper Mining Co., Butte, have a large

central air-compressing plant with a total capacity of 2,400 h p. In the first units they used induction motors, but in all the later units synchronous motors have been adopted, the largest unit being 1,200 h.p., three-phase, 60 cycle, 2,400 volts, 75 r.p.m. The choice of motor in this case has been influenced by the desire to raise the power-factor of their system, which includes many thousand horse-power of induction motors.

Power Required.—The power required for air compressing is a variable quantity, depending upon the amount of heat generated during the compression and the means for carrying it away from the compressor cylinders

An ideal compressor is one in which isothermal compression takes place, and the rule PV = a constant applies , when the compression of air takes place without external devices for carrying off the heat generated the compression is adiabatic. By water-jacketing the cylinders and providing an intercooler the isothermal line may be approached but never reached. In how far the isothermal line is approached depends upon the temperature and quality of the cooling water and the design of compressor.

Compressed air for mines is generally required for use at about 60 to 70 lbs. per square inch pressure, and the compressors are arranged for 80 to 100 lbs. per square inch to allow for losses in transmission, leakage, &c.

A compressor is rated by the volume of free air on the inlet side, *i.e.*, its low pressure piston displacement in cubic feet per minute, which displacement ought to be multiplied by the volumetric efficiency of the machine, although in catalogues this refinement is often omitted.

A good compressor will handle about 6 cub. ft. of free air per b.h.p. per minute and deliver it at 80 lbs. gauge pressure corrected for sea-level. At 100 lbs. gauge pressure the volume of free air handled would be about 5·25 cub. ft. per b.h.p. per minute.

A correction is required to determine the volume of free air at various altitudes, which, when compressed, is equal in effect to a given volume of free air at sea-level. At the usual working

pressures the multiplier is about 3·5 per cent. per 1,000 ft for altitudes up to 5,000 ft.

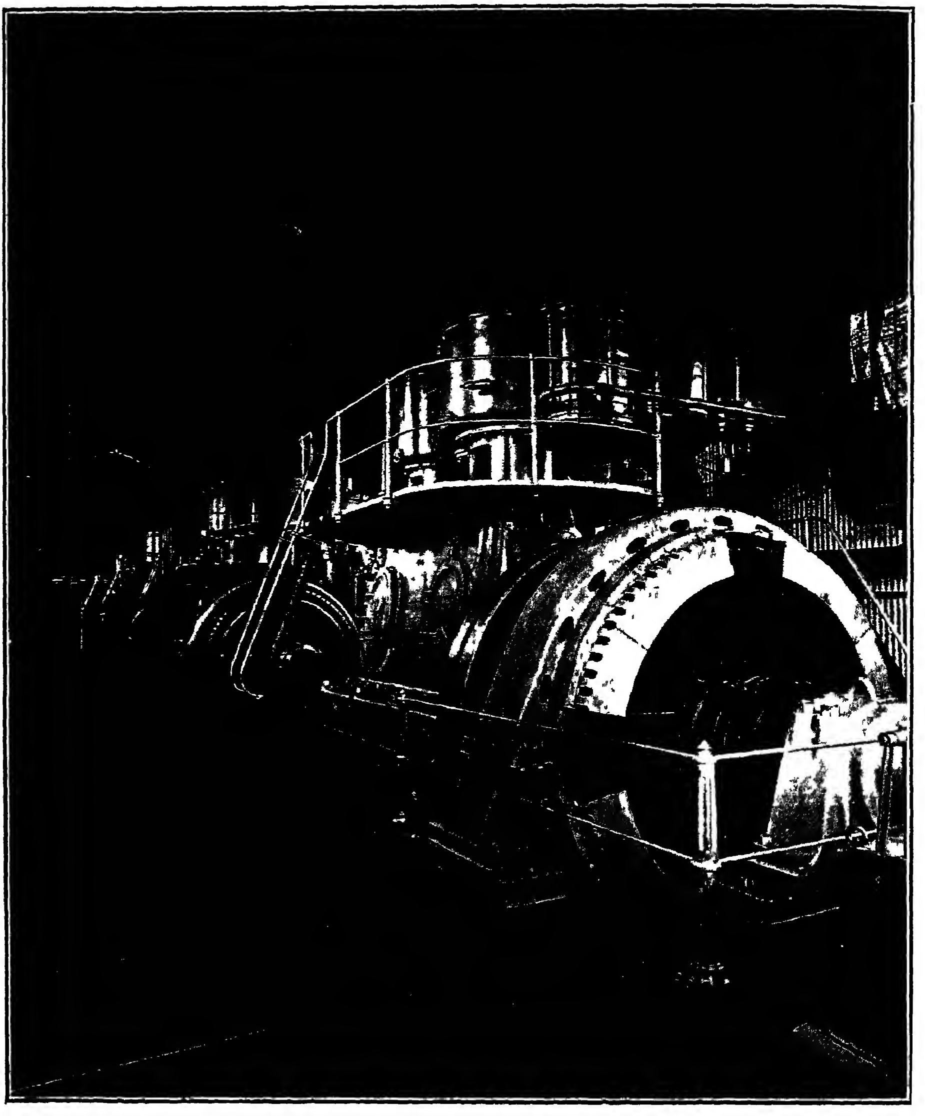


FIG. H8.—Belliss and Morcom's air compressor

Messrs. *Belliss and Morcom's* experience with high-speed engines has been turned to account in the design of their air

compressor, which is of the same general design as their well-known steam engine and readily adapted for electric driving. Fig. 118 shows an Air Compressor Station at New Modderfontein Mine on the Rand equipped with four Belliss and Morcom machines, each capable of compressing 6,500 cub. ft. of free air per minute to 100 lbs. pressure per square inch. These compressors are operated at a speed of 163 r.p.m. by Westinghouse three-phase induction motors capable of developing 1,000 h.p.

It will be noted that the motors are only provided with a single bearing, the arrangement in this respect being the same as the standard arrangement for direct coupling high-speed electric generating sets.

A very similar equipment is working at a South Wales Colliery and compressing 5,000 ft. of free air per minute to 90 lbs. pressure. The two-stage compressor is direct coupled to a Westinghouse 850 h.p. motor running at 187 r p.m.

A Belliss and Morcom-Sandycroft equipment to compress 5,000 cub. ft. of free air per minute to 81 lbs. per square inch pressure is interesting, as the motor is of the two-speed cascade type. Tests have been made on this set when driven at a constant speed and governed entirely by shutting a valve in the suction whenever the pressure exceeded 81 lbs. per square inch, and also with the set operated as a two-speed compressor, the speed reduction being reduced to two-thirds of full speed at 81 lbs pressure and the throttle closed at 82 lbs. pressure. At full speed when handling 5,000 cub. ft. of air the e.h p. per hour was 800 in each case, but at half-load when handling 2,500 cub. ft. per minute the e h.p. for the single speed motor was 460, as compared with 414 for the two-speed motor, a saving of 46 e.h.p., or 10 per cent.

Turbo-Compressors.— Prof. A. Rateau's licensees have turned out a large number of turbo-compressors, many of which are electrically driven. As mentioned earlier, while 25-cycle supply is satisfactory for many classes of motors, it imposes inconvenient speed limits for pumps and compressors. With 25 cycles, 1,500 r.p.m. is the maximum as compared with 3,000, which is the corresponding speed for a motor operating

on a 50-cycle supply. Double-helical gearing of the Wuest type running in an oil bath may be used to increase the speed of the motor shaft to the most suitable speed for the compressor, just as in other cases it may be used to reduce the speed. Turbo-compressors may be arranged in this way to deliver air against pressures from 15 lbs. to 100 lbs. per square inch, and so cover the complete range of requirements for blowing engines and compressors for power service.

In some cases Messrs. C. A. Parsons & Co. have supplied low-pressure turbo-compressors electrically driven and delivering air at about 20 lbs. pressure to work as first-stage machines in series with existing reciprocating compressors, thereby doubling the output of the reciprocating plant.

The Robinson Central Station of the Victoria Falls and Transvaal Power Co. is being equipped with six units, each of 4,000 h.p., which are to deliver compressed air into the Company's pipe-lines. Each unit is to handle 1,250,000 cub. ft. of free air per minute at 68° F. and to compress it to 128 lbs. per square inch. An isothermal efficiency of 64 per cent. was guaranteed for the machines and a maximum 4,200 h.p. at 3,000 r.p.m. The air compressors are of the Rateau type made by Messrs. Pokorny and Wittekind, the motors being supplied by the A. E. G. Co., of Berlin. The machines are illustrated and a test is given in *Engineering*, 15th December, 1911.

The electricity is taken from the Victoria Falls Power Co.'s mains. Synchronous motors were adopted, and owing to the difficulty in designing a synchronous motor for 4,200 h.p. each machine is made up of two motors; one motor shaft drives a low-pressure cylinder and an intermediate cylinder; the other motor drives a low-pressure cylinder and the high-pressure cylinder, the two motors and four turbo-compressors being arranged side by side on one combined bed-plate. The load was guaranteed to be balanced to within 5 per cent. between the two motors. In a test reported as taken at the makers' works in Berlin by Professor Langer the average horse-power was found to be 4,000 when handling 1,430,000 cub. ft. of free air per hour compressed to 115 lbs. per square inch. The highest isothermal compressor

efficiency was 67 7 per cent. with a temperature of cooling water of 52° F. When the cooling water temperature was 75° F. the compressor efficiency was 67·3 per cent. The isothermal efficiency is the energy ratio of the power required for isothermal compression to the power delivered to the shaft of the compressor, the compression taking place at an atmospheric temperature between the initial and the final pressure.

The *Reavell* high-speed **Quadruplex Compressor** is well

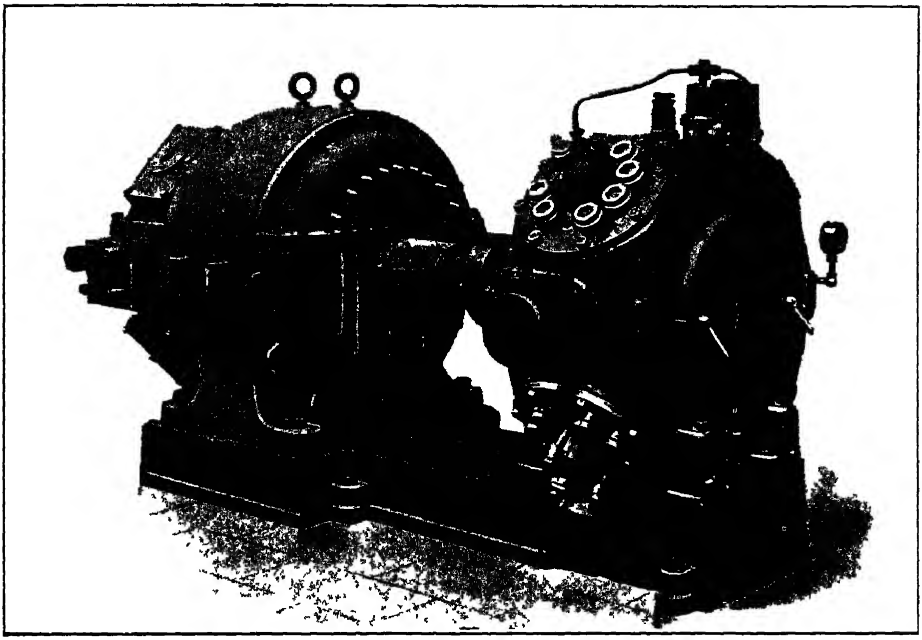


FIG. H9.—Reavell's air compressor.

adapted for electrical driving. Fig. H9 shows one lately supplied to a Yorkshire colliery company. The motor is totally enclosed, flametight and wound up for 500 volts continuous current ; it develops a normal load of 30 b.h.p. with a constant speed of 275 r.p.m., is capable of giving 45 to 50 h.p. for short periods, and is fitted with an oil-immersed starter. The normal working pressure is only 20 lbs. per square inch.

As mentioned in connection with Coal Cutters, the electrically driven machine has a much better output than the com-

pressed air machine, due, no doubt, to the low pressure at which the compressed air is delivered. Messrs. Reavell have supplied many of their machines for use in-bye, and in connection with them they have been investigating the question of the pressure actually used on coal cutters of the compressed-air engine-driven type. Mr. Reavell has informed the author that the result of their investigations has shown that, although it is the common opinion among the colliery officials that pressures of about 60 lbs. per square inch are necessary at the coal cutter, it is nevertheless a fact that the actual pressure usually found in the cylinders of a coal-cutting machine does not generally exceed 20 lbs. in ordinary working. The possibility of using this low pressure, of course, means an enormous reduction in the power required if the compressor is arranged to work normally at such pressure, and emphasises the advantage of in-bye compression in cases where the output from the coal cutter worked at these low pressures is sufficient.

The dust difficulty is a serious one, but could be overcome if the air pipes were arranged on a closed system, such as has been adopted in some instances in South Africa. The economical advantage is considerable, but the inconvenience of the double system of pipes acts as a deterrent from its more general adoption.

CHAPTER IX

PUMPING

As a chapter of ancient history it is interesting to remember that one of the earliest, if not the first, application of electricity for motive power in an English mine was the pumping plant at the Trafalgar Colliery, Forest of Dean, which was put in by Mr. W. B. Brain in 1882, and described by him in the Proceedings of the S. Wales Institute Eng., Vol. XIII., p. 277. A double-acting pump with a barrel 5 in. diameter by 8 in. stroke, working up to 60 or 70 strokes per minute, was put in, to take the place of a pump driven by a pair of horses, about 500 yards from the bottom of the shaft and about 90 ft. below it. The shaft was 200 yards deep and the pump nearly 600 yards from the generator on the surface The pump was provided with single reduction gearing and was belt driven by a 4 h.p. Gramme "A" size dynamo. Rubber covered, lead sheathed cable was used laid in a creosoted wooden box. The pump was usually left running locked up, a telephone and signal bell being fixed so that the engine driver on the surface could hear the pump working.

In May, 1887, a larger pump was started, and is described by Mr. Frank Brain (Proc. S. Wales Inst. Eng., Vol. XV., p. 363). This pump was 1,650 yards from the bottom of the shaft and handled 120 gallons a minute against a head of 500 ft. The pump had double plungers 9 in. diameter by 10 in. stroke and ran at 25 r.p.m. It had single-reduction spur gearing 6 to 1, and was connected by a belt to an Elwell-Parker 13 h.p. motor, 320 volts, 43 amps., 650 r.p.m. The cable, which was 2,000 yards long, was wrapped with compounded tape and supported by earthenware insulators 10 yards apart along the roads underground. In the shaft it was enclosed in wooden boxes. The return cable, which was earthed, was an old iron pit rope about $1\frac{1}{4}$ in. diameter. A telephone and signal bell were also

fixed in connection with this pump, but as it was larger it was deemed advisable to have a man in charge instead of locking it up as in the former case.

Duty.—Those who have not had practical experience with pumping plants have very little idea of the duty of a pump or what a stream of water weighs. In approximate figures a feeder of 155 gallons per minute, say 25 cub. ft., is equal to 1,000 tons of water in 24 hours. A pipe of 5 in. diameter would carry this supply at a velocity of 200 ft. per minute. One thousand tons a day of mineral is a good output, but 1,000 tons of water may very readily be met with, and it is only the ease and continuity with which the water can be handled that makes the pumping plant insignificant as compared with the plant for winding mineral. In some cases, however, the cost of pumping is very high; it is said that in some of the South Staffordshire mines, where a joint pumping scheme handles the water for a large area, the cost of pumping is equal to $9\frac{1}{2}d$ per ton of coal raised.

The amount of water to be handled varies over very wide limits. Table J1 shows a schedule of pumps which are used in a group of pits raising about two million tons of coal per annum, and which may be classed as fairly dry. The aggregate horse-power of the twelve pumps is 664; some of them are very little used.

TABLE J1.

Pit	Position	Motor H.P.	Type of Pump	Duty.	
				Gallons per Minute	Feet Lift
No. 1	Sump	30	3 Throw ..	45	1,380
No. 2	Sump	30	,, ..	45	1,002
No. 2	Lower Lodge ..	50	,, ..	170	550
No. 2	Upper ,, ..	60	Centrifugal	300	337
No. 3	Sump	80	3 Throw ..	100	1.410
No. 3	Lower Lodge ..	20	,, ..	45	675
No. 3	Upper ,, ..	110	Centrifugal	500	420
No. 3	Upper ,, ..	65	3 Throw ..	300	420
No. $3\frac{1}{2}$	Sump	35	Centrifugal	150	450
No. 4	Sump	50	3 Throw ..	100	800
No. 5	Special Pumping Station ..	62	Centrifugal	150	360
No. 5		62	,,	80	1,260

Contrasted with this, in another pit in the same neighbourhood, where the capacity is 450,000 tons of coal per annum, the pump horse-power amounts to 300, and is well occupied.

It is perhaps putting it not at all too high to say that the heavy pumping which is necessary to keep down the water in the Powell Duffryn Pits, in South Wales, has very largely contributed to the success of the gas engine plant installed there. The quantity is so great that two 950 h.p. pumps are required and are run at night to equalise the load on the gas engines.

Head.—A point which should be remembered is that the head or lift not only includes the suction lift and the lift above the pump, but also includes the pipe friction, which should be kept as low as possible in view of capital cost and the cost of power.

If the quantity of water to be lifted is very small and the head is high, a plunger pump can be employed, while, as will be dealt with later, a centrifugal pump might be impracticable owing to the high speed or the number of stages that would have to be employed and the excessive friction in the small water passages.

Air Vessels.—The ram type of pump when used for high lifts requires an air vessel to relieve the pipes from shock and to make the flow of water approximately constant.

In a centrifugal pump there is no necessity to provide an air vessel, as the water comes from the pump in a constant stream, this not only relieves the pipes and valves from all shock, but allows a smaller section of pipe to be employed.

Dirty Water.—The class of water to be handled has also to be considered, as its corrosive effect may render certain types of pump impracticable. Large slow-speed pumps will handle a surprising amount of grit and dirt, particularly if they are of the plunger type, but with small high-speed, reciprocating pumps every effort should be made to keep grit out of the pump, which can be in a great measure effected if settling tanks are provided and cleaned regularly.

Large, low-lift centrifugal pumps are commonly used for suction dredgers, the intention being to remove sand or ballast with no more water than is necessary to transport the ballast. The clearance in these pumps is large, and they give complete satisfaction.

With high-lift centrifugal pumps the conditions are altogether different, the clearances are smaller; and although such pumps have been used to handle water with a considerable amount of sand in suspension, wear and tear is necessarily greater, but by no means excessive in the best types.

Sinking pumps of this description are referred to later. In this type, particularly, the small space occupied by the high-lift centrifugal and the convenience with which it can be fixed and worked are often sufficient set-off against the disadvantage of greater wear and tear than obtains in other types of pump.

The ram pump has an advantage over the centrifugal type when the water supply is intermittent and air is liable to enter the suction, as in a dip pump working close to a face, or in unwatering a small working place. Then the pump is what the miner happily calls "working on snore," and while a ram pump can pull a vacuum under these conditions a centrifugal pump requires recharging and is troublesome.

Electric Driving.—Some of the earliest applications of electricity to driving mine pumps in Germany consisted of a large slow-speed motor mounted directly on the shaft between two overhung cranks which actuated the pumps, the pump cylinders being of precisely the same type as would be used for steam pumps. In some cases the equipment included a steam engine and a three-phase generator on the surface. To start up the pumps in the mine all the switches were closed and the engine stop-valve opened when the generator and motor came up to full speed together, any subsequent regulating being done on the engine governor or by a delivery valve on the surface. This, with small generating units, was convenient, but the arrangement is not efficient as compared with pumps working in parallel off a large power station, although it forms an interesting step in the development of electric driving.

The position of the engine relative to the pumps driven by it

was settled in the case of the Cornish pumps, as in view of the size of the engine fixing it on the surface was compulsory. Reciprocating pumps, as constructed for steam, were placed underground and driven by steam or compressed air. An attempt to get over the heavy losses on such an arrangement was made, particularly in Scotland, by transmitting the power to the pump by a wire rope-drive. Where the roads were fairly straight such arrangements did not give much trouble through wear and tear, but were not high in efficiency.

It is a short step from driving a pump by wire-rope transmission to an electric wire transmission. The wet and dirty places in which pumps are frequently put to work are not at first sight favourable to electric driving, but in many cases such conditions can be removed and a suitable pump-house constructed which is quite a fit and proper place for an electric motor. If the pump-house is so situated that it is likely to be drowned, a special construction of motor has to be used. Motors are now available which will work absolutely under water, but all motors are not amphibious, although with the modern water-proof construction many motors will withstand conditions which some years ago would have been looked upon as impossible. The risk of drowning a pump is sometimes very real, and has to be taken into account in the design of the plant.

In the case of some recent unwatering operations, owing to faulty manipulation of the valves, a Cornish pump was drowned to a depth of 78 ft. The pump would work, but could not be run faster and thus lower the water, so eventually a diver was sent down the ladder-way alongside the pipes, and on the second attempt closed the valve which had been inadvertently opened.

In another case of rod-pumps, reported at the Inst. Civ. Eng. Conference, 1907, three were being put down to lift 8,000,000 gallons of water a day to a height of 2,000 ft. One pump had only just been started, when the water broke in and drowned the pump to some 200 ft. in depth. The drowned pump had to be run continuously for about two months until the water could be got out.

Cornish pumps and three-throw pumps driven by wire-rope transmission have been run drowned for weeks, but with an

electric motor it is another matter, and it is better to provide duplicate pumps rather than to run the risk of the damage to the pit and workings which may be the result of drowning.

Electrical Problem.—The electrical driving of pumps does not present any difficulty. In the early stages when slow-speed steam-driven pumps were being converted to electrical drive, difficulties were sometimes encountered to meet the slow speed, as it entailed a motor with a large number of poles and of large dimensions; hence gearing, with frequently a belt or rope speed reduction, was employed. Since the speed of pumps has gone up this difficulty has nearly disappeared, so that direct coupling or single reduction gearing can generally be employed. As, ordinarily, no speed regulation is required and no abnormal starting torques are called for, standard designs of motor can be utilised.

In cases where the available motor speeds are not suitable for direct coupling, gearing, belt or rope-drive may be used. For large centrifugal pumps the belt pulley should be on a separate shaft connected to the pump by a flexible coupling to prevent distortion of the pump shaft.

With flexible belts high speeds may be used; as an instance, a belt running 7,050 ft. per minute and driving 110 h p. on a pulley only 13¼ in. diameter may be mentioned. The belt is 8 in. wide, sewn endless, orange tanned, and water-proofed. It ran one-and-a-half years, or 1,500,000 miles, without any trouble, and at the end of this period appeared as good as new.

In most cases pumps have to work in unfavourable localities; this chiefly accounts for the popularity of the three-phase induction motor for driving them. Although the motor presents no special features, care must be exercised in the choice of the starting apparatus, which must be adequate for the starting torque required by the motor.

Speaking generally, plunger pumps require a starting torque up to about twice the normal full-load torque, whereas centrifugal pumps when started up with closed delivery valve and bye-pass require only 30 to 40 per cent. of the full-load torque; hence for plunger pumps a slip-ring motor is preferable to keep down the starting current. For centrifugal

pumps, on the other hand, a short-circuited rotor motor will answer the purpose, as 30 to 40 per cent. of full-load starting torque will require a starting current not much above the full-load running current.

Motor Cooling.—When the motors require cooling the matter must be carefully considered. In some cases motors have been cooled directly by water jackets, in which case it is better to have a small pipe branching from the main and delivering to waste, so that the jacket is under the lowest possible pressure. If the motor is jacketed and the main delivery is passed round it, as has been done in some cases, an undue pressure is put on the castings, which causes destructive sweating and deterioration of the motor.

A better way to cool a motor is by forced ventilation, in which case the motor and air circuits are enclosed The air is driven through cooling coils and then through the motor and so circulated over and over again. Motors cooled on this system are at work in the Comstock Mines in Virginia, where the water pumped has a temperature of about 175° F. at a depth of 2,500 ft. below the surface. The water for the cooling coils is taken down from the surface.

Speed Regulation is not generally called for, as lodge rooms or sumps can be formed for water storage in such quantities as will give the pump full load for some hours run. It is often advisable to arrange special water storage, so that the pumps may be run at such hours as may be necessary to level up the load on the power plant.

Sometimes, however, variable speed has been found necessary.

With a continuous current motor, the speed regulation is simple, but with alternating current the usual difficulty arose, which was met by mechanical means or by bye-passing the water.

The author saw an interesting mechanical arrangement in Silesia a short time ago, where two three-throw pumps were running driven by three-phase motors at constant speed and arranged so that they would deliver either 1 cub. metre or 2 cub. metres of water per revolution. The pump barrels are

double concentric, both the barrels being provided with a heavy packing gland and also with lugs. The lugs on the outer barrel can be bolted alternatively to corresponding lugs on the slides or on the inner barrel, so that the outer barrel either acts as a pump barrel or as a ram, the areas being such that the displacement gives the desired cub. metre or 2 cub. metres respectively per revolution of the three rams.

Remote Control.—Messrs. Laurence Scott & Co., Ltd., make a speciality in the remote control of continuous current motors for the Admiralty, and have applied some of their experience gained on warships to the control of motors in mines. In the case of a pump for keeping down the water in a lodge-room the starting and stopping are both effected primarily by the position of a float, which closes the contact on an appropriate relay, and a second switch may be operated by a further relay, which will accelerate the speed of the pump if the water rises above a predetermined normal level. Their automatic starter consists of a series of relay switches with a solenoid operated "discriminator" for working with them, and enclosed in the same case is the automatic shunt regulator. The makers do not attempt to employ a floating shunt regulator, as they have found in practical work that they are not satisfactory. They prefer for this purpose to use one step only for speed regulation, but the resistance may be inserted as slowly as is desired so that the pump may be accelerated without mechanical shock or a sudden rush of current.

Cornish Pumps.—The most popular type of pump for mine drainage for many years was the Cornish, in which the pumps are actuated by a steam engine through the medium of rods. These pumps are arranged either to lift (*i.e.*, of the bucket type), to force (*i.e.*, of the plunger type), or a combination of both. They are invariably of the long-stroke, slow-speed type and have been built in units up to 1,200 or 1,500 h.p. The pumping engine is sometimes placed immediately over the shaft, and actuates the pumps directly by vertical rods from the end of the beam. In other cases the beam works a crank which gives a reciprocating motion to the pumps through long lengths of

connecting rods. At the slow speeds obtaining say, six to nine double-strokes per minute, the wear and tear is very small, and such pumps have given the greatest satisfaction for many years. A great objection to them is the large space taken up by them in the shaft and the inconvenience in getting at them when repairs are necessary. They have, however, won such favour in the mining field that engineers in some quarters are still loath to depart from them and

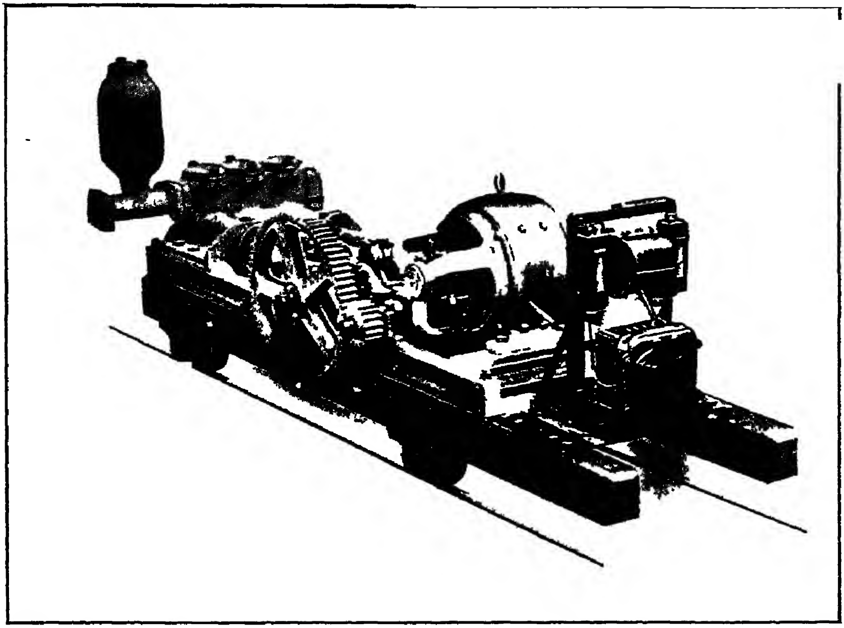


FIG J1.—"Uskside" dip pump

adopt anything in the nature of a high-speed pump. Cornish pumps are sometimes geared, but the relatively high speed of electric motors naturally calls for a high-speed pump, as the loss in gearing to drive such slow-speed pumps by electric motors may be considerable, and the great advantage of high-speed machinery in the decreased space occupied by it would be lost.

Following the Cornish pump came the direct-driven type of pump, in which the steam cylinders and pumps are in one line.

Pumps driven direct from a crank-shaft running from 30 to 45 r.p.m. were also developed, and a pump of this kind was, as already mentioned, the first to be driven electrically.

Ram Pumps.—Fig. J1 shows a very useful type of dip pump mounted on a small truck for convenience in transport This type of portable pump is made by the Uskside Engineering Co. in several sizes from $2\frac{1}{2}$ in. rams by 6 in stroke up to $5\frac{1}{2}$ in. rams

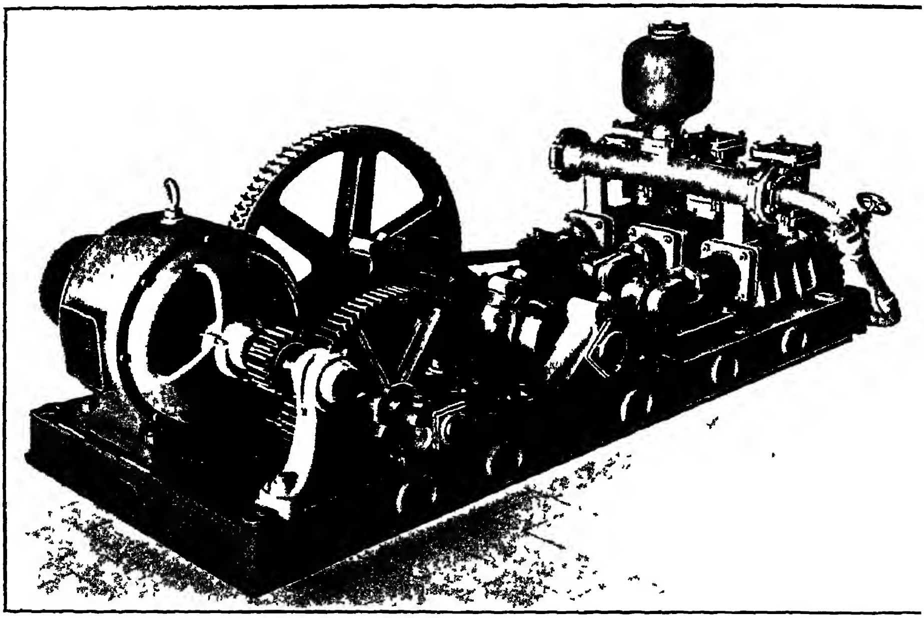


FIG. J2 —"Uskside" three-throw pump.

by 8 in. stroke. The figure shows a pump with rams 4 in. dia by 8 in. stroke, which run at a speed of 45 double strokes per min, and will deliver 50 gallons per minute against a vertical head of 250 ft. The valve-box chamber is cast in one piece with the barrels, and is fitted with gun-metal valves and seats; the plungers are also of gun-metal, and are attached to slipper cross-heads. The main gearing has machine-moulded teeth, the first motion machine-cut teeth. The bed-plate is of cast iron and made in sections. The pump, with its 5 h.p. motor and

starting gear, is self-contained and mounted on a timber trolley provided with wheels and axles to suit the gauge of the mine.

Fig. J2 shows a high-lift reciprocating pump of the three-throw type in use in a Staffordshire mine. This pump is a standard type made by the Uskside Co., and is of very substantial design. The chief features are the four-bearing crank-shaft, and the barrels and valve-boxes are all made independent and interchangeable. The three rams are 7 in. diameter by 9 in. stroke and run at 42 r.p.m. The pump delivers 150 gallons a minute against a vertical head of 1,300 ft. The first motion gearing is machine-cut with a raw-hide pinion; the main gearing is machine-moulded. The efficiency of this pump from output of motor to the water delivered is 81 per cent.

While in England the three-throw pump has been the usual standard, in America quintuplex mine pumps have been made, a good example of which is the Aldrich vertical pump made for the Anaconda Copper Mines This pump is designed to deliver 425 gallons per minute against a vertical lift of 1,200 ft. It has five single-acting plungers operated by one crank-shaft. The steady delivery given by the five plungers renders the use of an air chamber unnecessary, and the steady torque and continuity of discharge is claimed as a high factor in the efficiency The water contains grit and is highly charged with sulphate of copper, consequently the water ends have to be made of a high grade acid-resisting bronze. The pumps are fitted with a bye-pass, which enables the motor to be started without load. The pumps are driven by a Westinghouse alternating current motor of 150 h.p. capacity at 450 r.p.m. through single reduction spur gearing, the motor standing on the floor alongside them. A test showed an overall efficiency of 80 per cent. between the current delivered to the motor and the water discharged to the surface.

The speed limitation in reciprocating pumps is due to the slamming of the valves and the changing of the direction of the plungers. Various steps have been taken to overcome this difficulty, notably on the Continent, where positively controlled valves and special shapes of plungers were introduced, as in the Riedler pump and the Gutermuth pump, which have been

developed abroad, but are made in this country by Messrs. Fraser and Chalmers, Ltd.

Professor *Riedler*, whose name is closely identified with pump work of various descriptions, studied the cause and effect of the shocks and slamming common in the ordinary reciprocating type of pump when run at high speeds. He found greater throttling or resistance in the valve passages than had been previously recognised, and he further found that slip was the main cause of the slamming. He decided that one large valve was better than several small valves, and arranged that while the valve is automatically opened its opening is controlled by a mechanical device and it is positively closed before the plunger starts on its return stroke. By this means he diminished both the throttling and the slip, and by a combination of this arrangement of valve with a differential plunger he developed a pump with a single plunger and two valves, which he found could be run at a high rotative speed and gave a better efficiency than a three-throw pump of equal volume, as the flow of water was steadier and there was only the friction due to one plunger and two valves instead of three plungers and six valves.

One end of the differential plunger is twice the area of the other end. The large plunger discharges the whole of its water through the delivery valve on the indoor stroke. There is a supplementary chamber adjoining and connecting the delivery valve with the small plunger, so that half of the water is sent into the delivery pipe and the other half into the supplementary chamber. On the outdoor or suction stroke the difference in area of the small and large plungers discharges the contents of the supplementary chamber into the delivery pipe. By this method a double-acting pump is obtained with only two valves.

The *Riedler* pump, with a single differential plunger to deliver 68 gallons a minute against 1,000 ft. head, can be run at 150 r.p.m. A similar pump of ten times the capacity would be run at 80 r.p.m. These high rotative speeds make the pump peculiarly suited for electric driving.

The *Gutermuth* pump is particularly notable on account of the type of valve employed. The Gutermuth valve is made by

coiling a sheet of metal in a way very similar to a clock-spring. The valve is simply slipped on to the spindle and its inside edge is held in place by clamps, so that its action is altogether different from any other type of valve. When opening or closing it has a wiping motion, and, due to its extraordinary flexibility and small resistance, a full port opening is readily obtained.

Pumps with this type of valve and differential plungers are made in one, two, or three plunger models, running at speeds up to 250 r.p.m. For instance, a pump delivering 200 gallons per minute against 900 ft. head can be run at 250 r.p.m., and a pump to deliver 1,000 gallons per minute against 750 ft. head can be run at 180 r.p m.

High-Lift Centrifugal.—The development of the High-Lift Centrifugal Pump has been very important from the electrical engineer's point of view, and it is of great importance also to the mining engineer owing to the ease with which it can be handled as compared with any other type of pump for equivalent duty.

The high-lift centrifugal pump consists essentially of several centrifugal pumps in series In the earlier examples separate pumps were actually fixed in series, sometimes on the same spindle, and sometimes at different levels, the lowest pump being arranged to deliver into the suction of the pump above it, and so on, as at Horcajo. The only disadvantage in this arrangement is that the lowest pump has to withstand the full pressure, whereas if each pump delivers into an open lodge from which the next pump above it takes its suction, each pump has only to withstand the pressure due to its own lift.

The development of the pump, in which several impellers are arranged in series on the same shaft, is greatly due to Messrs. Sulzer Brothers, who claim to have been the first to use guide wheels in which the velocity of the water discharged by the impellers is converted into additional pressure, and who built the first successful plants on these lines. Other makers have since been busy in the same direction, and high-lift centrifugal pumps with several impellers in one casing are now obtainable from many different makers. The impellers are

arranged in series for pressure stages and in parallel for quantity. Fig. J3 shows a section of Messrs. Sulzer's Standard pump.

The chief difference between the low-lift and the high-lift centrifugal is in the arrangement of these guide wheels, by which the efficiency of the pump is greatly increased. With a low-lift pump delivering against a head of 60 ft. is a good performance; the addition of the guide wheel enables lifts of about 350 ft. to be accomplished with one impeller for volumes of 1,400 to 3,500 gallons per minute.

In the earlier models the impellers were arranged in pairs

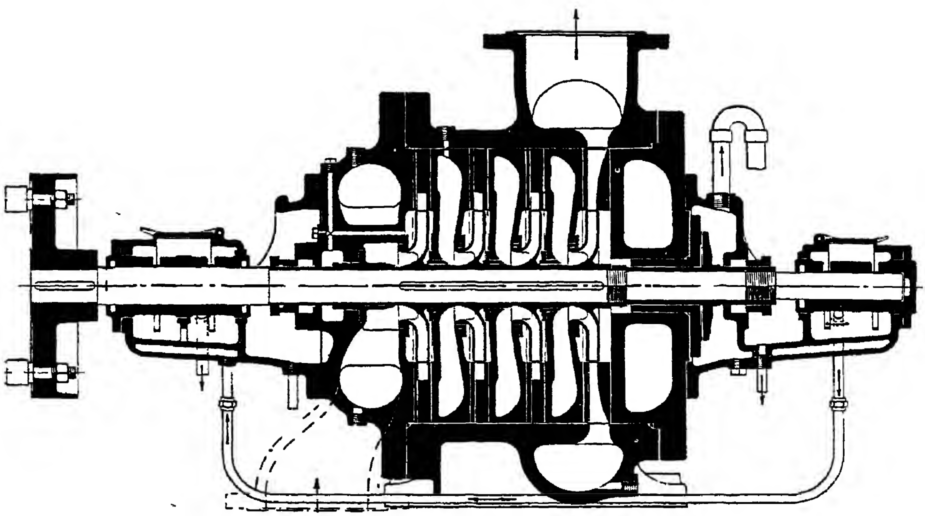


FIG J3.—Sulzer's centrifugal pump. Section

back to back in order to neutralise the side thrust, each pair being surrounded by one double guide wheel with spiral channels very carefully formed and finished. Between the pairs of impellers intermediate guide pieces were arranged. In most of the later models all the impellers take the water from the same side, and the balancing is effected by a disc, the action of which is automatic. Another device adopted is to make half the impellers take water from one side and the other half from the opposite side, but this, like the original method, is inconvenient, as it calls for an even number of impellers.

The diffuser passages and channels call for very careful design to avoid eddy currents and air chambers, and the use of

special materials highly finished is necessary, not only to minimise the friction losses, but to decrease the wear and so prolong the life of the pump. The tardy appreciation of these constructional points was perhaps the outstanding difference between different makes of pumps. For years past makers of agricultural implements have made centrifugal pumps, and unfortunately it has been too often considered that several of these, arranged in series, might be sold as a high-lift centrifugal pump !

Possible Volumes and Heads.—The diameter of the impeller must be in a certain proportion to its speed, to the lift, and to the quantity of water to be delivered, so that there are limitations in the possible efficiency for high lifts. If the quantity of water is small in relation to the head, a good efficiency is impossible.

From the particulars supplied by Messrs. Boving & Co. for High-Lift "Victoria" pumps at 1,450 r p.m. about 120 gallons per minute is the minimum volume that can be efficiently handled, and this can be delivered against a 328 ft. head with a ten-stage pump. For general guidance they suggest that

265	galls. per min.	can be lifted	420 ft.	with an	8-stage	pump
440	,,	,,	700 ft.	,,	7	,,
815	,,	,,	1,058 ft.	,,	7	,,
1,160	,,	,,	1,200 ft.	,,	6	,,

As the volume increases the restrictions as to head are decreased and the problem of efficient design becomes easier.

Messrs. Sulzer have delivered ten eight-stage pumps each delivering 1,320 galls. per minute to a height of 2,275 ft., at a speed of 1,480 r.p m. and an efficiency of 75 per cent., the power on the pump shaft being about 1,230 h.p.

There is a limit to the number of impellers or stages that can be arranged in one casing; when this limit is reached two pumps can be arranged in series.

If importance is attached to high efficiency Messrs. Sulzer recommend the volume be not less than 130 gallons per minute for lifts below 820 ft. and 220 gallons per minute for lifts above 820 ft. Although these may be the limits where high efficiency

is sought, and may be taken as the general commercial limits, it must be remembered that they are not the binding mechanical limits. The advantages of the high-lift centrifugal pump, such as small space occupied, light weight, small foundations, &c., are important, and may often decide the matter in favour of the centrifugal at a small sacrifice of efficiency.

Regulation.—The regulation of a centrifugal pump is not

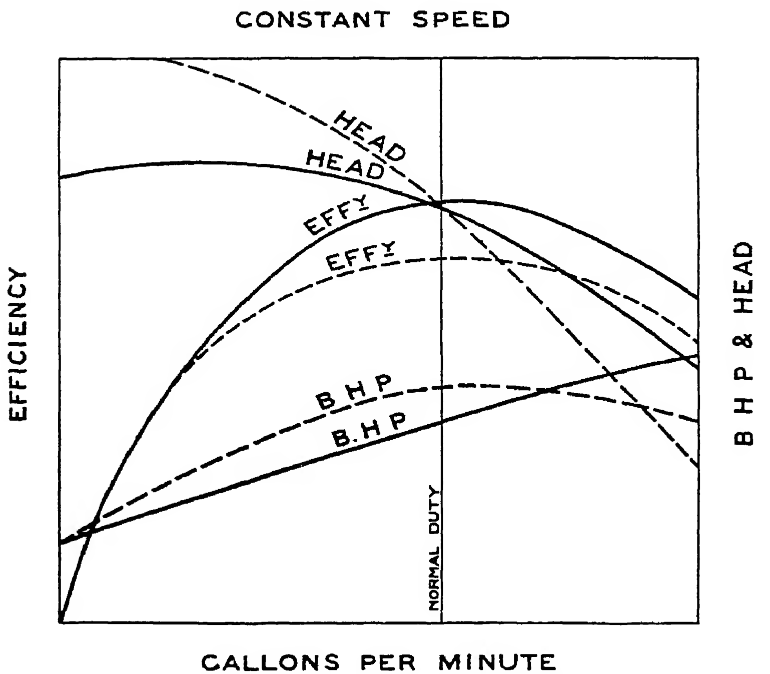


FIG. 34.—Characteristics of normal and special centrifugal pumps.
Normal shown by full lines.
Special ,, ,, dotted lines

quite so convenient as that of a three-throw pump, as there is a critical speed below which it will not lift any water against the required head. The volume varies approximately as the speed, and the head as the square of the speed, and the power required for driving the pump increases approximately as the cube of the speed.

A certain amount of regulation may be conveniently obtained by adjusting the delivery valve. If the speed is not absolutely

correct for the head under which the pump is working, opening the delivery valve too much may overload the motor. On the other hand, if the quantity of water to be handled is less than the normal, the partial closing of the delivery valve will not put a dangerous pressure on the pump casing. In any case, such pumps must never be allowed to run dry, and if the pump is run with the delivery valve closed long enough for the water to become hot the pump may be damaged.

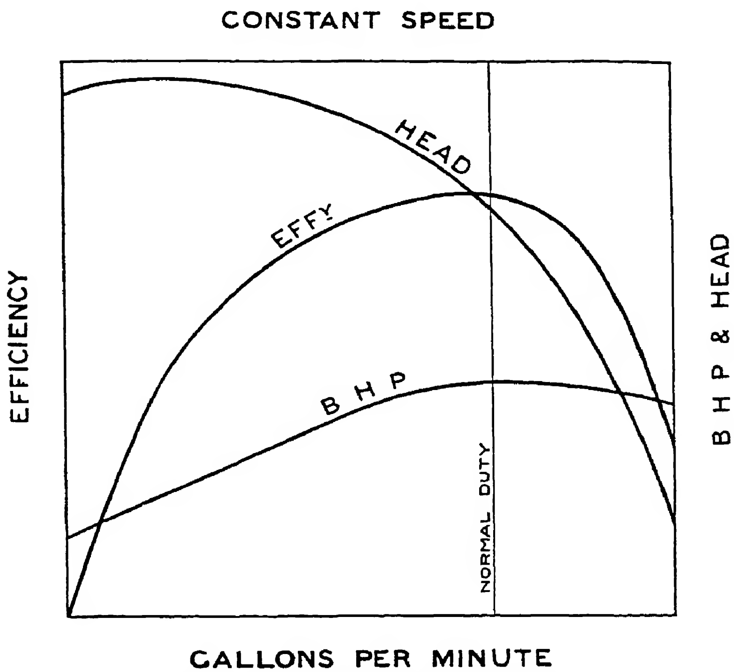


FIG J5 —Characteristics of Allen's "Conqueror" pump.

Self Regulation.—The question as to whether decreasing the head on the pump will increase the power absorbed by it and overload the motor depends upon its design and the size of the pump chosen for the normal duty, and the presence or absence of this feature is not a special characteristic in the pump of any particular maker. The effect is obtained by specially designing the impellers with small nozzles or constricted water ways and at some sacrifice of efficiency.

When a pump has to work at constant speed with a varying

head this disadvantage is outweighed by the greater flexibility in working. A self-regulating pump has its efficiency curve flatter and lower than a normal curve, and its b h.p. curve falls away somewhat rapidly on each side of the point of maximum efficiency or normal rating, while a non-regulating pump has a higher efficiency curve, and a b.h.p. curve which rises up to the point of normal rating and goes on rising beyond that point. In each case the volume of water is increased, but in the self-regulating pump the power for a constant speed does not rise beyond the fixed limit, no matter how much the head is reduced. Fig. J4 shows the curves of the two types.

This point is well illustrated in Fig. J5, which shows the performance of one of Messrs. W. H. Allen, Son & Co.'s "Conqueror" pumps, normally rated at 1,400 gallons per minute and 37 ft. head, and specially designed for constant speed and varying head. This pump will work against a head varying from 48 ft. to 10 ft, delivering a quantity of water varying from 500 to 2,000 gallons per minute. The power absorbed is 13 b.h p. at 48 ft, and as the head falls the b.h.p. gradually rises, attaining the maximum of 20 5 b h.p. at the 37 ft. head, which is the normal rating for which the pump is designed. As the head falls further the power absorbed commences to decrease and falls to 18 b.h.p. at 10 ft. head.

It is always safer to take care that the motor coupled to a centrifugal pump is sufficiently large. The following rule for the size of the motor in comparison with the shaft horse-power of the pump is that adopted by a leading maker, and may be convenient for reference :—

The motor to be larger than the pump,

Up to about	5 h.p. output	by	50	per cent.
,,	30 ,,	,,	25	,,
Over	30 ,,	,,	10	,,

High-lift centrifugal pumps are frequently now used for boiler-feeding purposes, in which case they have a curve similar to that shown of the "Conqueror" pump.

It is seldom that speed regulation is required with a pump designed for regular duty, so that a three-phase motor lends itself very well to driving centrifugal pumps.

Special attention must be paid to the starting torque problem. In order to keep down the torque the pump is sometimes fitted with a bye-pass, although the closed delivery valve is generally sufficient for the purpose. As soon as full speed is reached the delivery valve is opened.

To speed up a centrifugal pump on closed delivery valve a maximum torque of about 30 per cent. the normal full-load torque is required. As the ordinary squirrel cage motor can develop 30 per cent. full load torque with a current approximately equal to full load current, this type of motor is generally adopted. It is hardly possible to imagine anything more reliable and less apt to get out of order than a well-made centrifugal pump coupled direct to a squirrel cage motor, owing to the absence of reciprocating parts and the small number of working parts or bearings.

The Rees-Roturbo pump differs from other centrifugal pumps in the design of its rotor, which instead of being built as a flat disc with the object of securing velocity of water in the expanding channels of the casing, is designed in the form of a drum, having partitions which carry the water round with them and set up in it a centrifugal force, which drives it through the backwardly curved nozzles in the periphery of the drum. The water then, still having a high velocity in the direction of rotation, passes through the diffuser channels, which convert the velocity into pressure. The makers claim that the water passing through the nozzles behaves as in a turbine, assists the rotation of the drum, and has a self-regulating effect. The makers use as their standard double-sided impellers; this design does away with end pressure, but for high lift necessitates a long shaft.

Horcajo Pumps.—One of the earliest applications of the high-lift centrifugal pumps to mine drainage is the installation in the Spanish Mine of Horcajo, which was started by Messrs. Sulzer Brothers early in 1900. It originally consisted of three direct-coupled electrically driven pumps, fixed at different levels, and connected in series. Each pump handled 925 gallons per minute, the total head over the three pumps being 1,275 ft. Subsequently the shaft was sunk to a deeper

level and two more pumps were erected and similarly connected up. The complete plant now discharges 1,142 gallons per minute, with a total head of 1,970 ft.

As an indication of the reliability of high-lift centrifugal pumps, it is interesting to note that the resident engineers at the mine tested the plant after it had been working for one year, when the efficiency was found to be 76 per cent. After it had been working five years, during which period it had only been stopped for sixteen hours a month, the test was repeated, and the efficiency was again found to be 76 per cent. The larger plant was tested at a later date and the efficiency found to be 79½ per cent.

The Horcajo plant is of special interest, as it is claimed to be the first instance where motors with short circuited rotors were used for driving centrifugal pumps connected in series on to one rising main. Another point of interest is that the motors are all started from the surface by one and the same auto-transformer. To be able to do this each motor must have its own cable, and a special set of starting bus-bars must be provided. Each motor is successively run up to speed on the starting bus-bars and then switched over on to the main bus-bars. In addition to the cables for each individual pump a common stand-by cable connected to a set of links in each lodge is provided. A special feature of the motor is the waterproof insulation, which has proved very efficacious in one instance, when, owing to the breakdown of the old pumping engine, one of the motors was submerged in water for several hours. After being dried by a charcoal fire the motor was put into commission again without showing any injurious effects.

Rauxel Test.—A useful test showing the efficiency at the various stages of a complete high-lift centrifugal pumping plant was made at the Victor Mine, Rauxel, in the Ruhr district, where a Sulzer steam engine running at 113 r.p.m. drives a three-phase, 53-cycle alternator. The pumping plant consists of two Sulzer high-lift centrifugal pumps connected in series. Each pump is driven at 1,035 r.p.m. by a motor rated at 600 h.p. The pumps were designed for a duty of 1,900 galls.

per minute lifted 1,700 ft The following figures were obtained on a test published in *Gluckauf* in 1904 .—

I.h.p. of engine	1310.
Efficiency $\frac{WHP}{IHP}$	58·79 per cent.
Efficiency at the various stages :—	
Engine, excluding condensing and excitation	90·09 ,, ,,
Engine, including condensing and excitation	88·50 ,, ,,
Generator, excluding excitation ..	95·74 ,, ,,
,, including ,, ...	94·14 ,, ,,
Cables	99·26 ,, ,,
Motors	94·40 ,, ,,
Pumps, including rising main ..	75·47 ,, ,,
Combined efficiency of motor and pumps	71·25 ,, ,,

Ferndale.—An interesting arrangement of centrifugal pumping plant was designed by the author to deal with the water from a group of four pits, and was described by him in 1909 (Proc. S. Wales Inst. Eng., Vol. XXVI., p. 892). Fig. 76 shows diagrammatically the position of the pumps in the workings and a plan showing the relative position of the pumps and motors. The two pumps are placed in a heading near the sump of No. 4 shaft ; normally one pump deals with the water from the three sumps, it being piped and allowed to run down to No. 4 sump by gravity. The second pump deals with the water from the lodge-room in No. 3 shaft and the lodge-room in No. 4 shaft, the suction pipes being connected together to a Y piece before they join the pump. The pump-room is about 1,210 ft. below the surface. The head of water on the suction side of the second pump, due to the position of the lodge-room in No. 3 shaft, is 955 ft., so that the actual head is 1,210 — 955 = 255 ft., and the pump is working at the bottom of a U tube. The lodge-room in No. 4 shaft is at a higher level than that in No. 3 shaft, so that the water from the two lodges cannot be handled at the same time, and to

prevent water running back from the higher into the lower lodge a non-return valve is placed in the main.

The arrangement in the pump-room consists of two similar pumps placed at 40 ft. centres with two identical motors

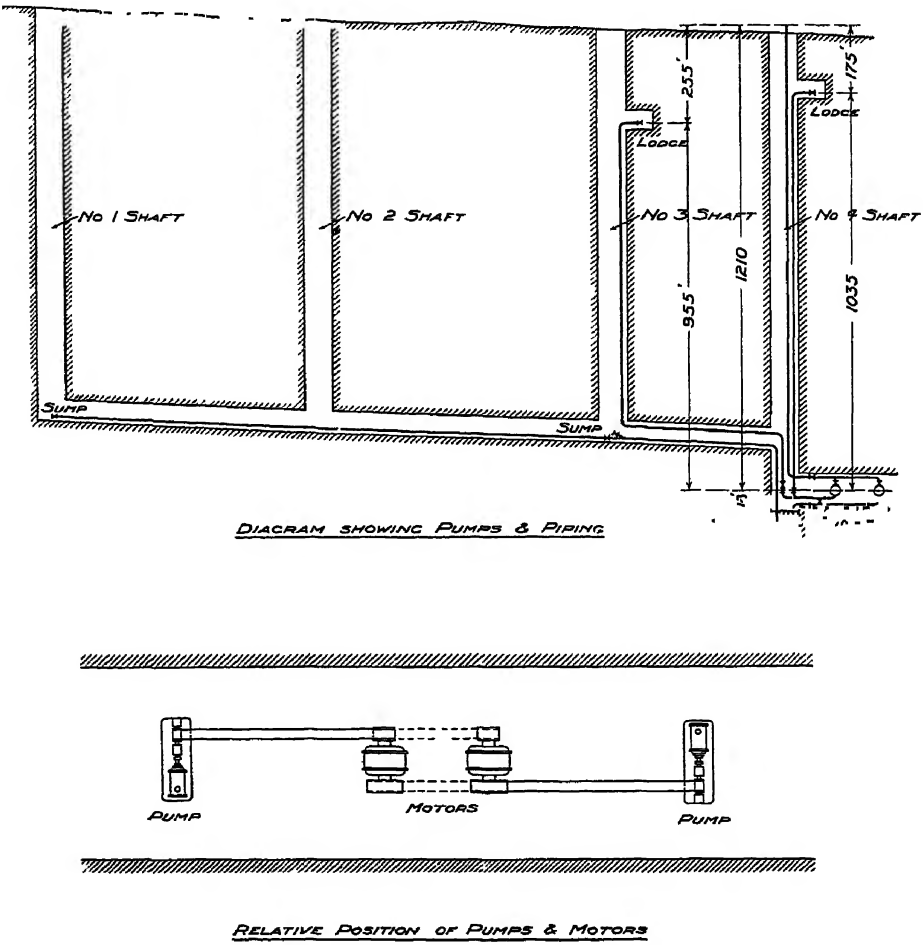


Fig. J6 —Central pumping plant for four shafts

between them, each motor being provided with an extension shaft and two different-sized pulleys. This arrangement was adopted for the sake of duplication, but at a small expense in efficiency. By a simple arrangement of valves either pump can be put on either duty in case of an emergency, but as the

heads and volumes for these duties are different the pumps are run at different speeds, depending on the duty required, the change of speed being effected by altering the diameter of the motor pulley.

The pumps are of Messrs. Sulzer's High-Lift Centrifugal eight-stage type. The motors are by Messrs. Lahmeyer, three-phase, 25 cycles, 2,200 volts, giving 62 b.h p. at 720 r.p.m. The motors are mounted on slide rails, and drive the pumps by means of leather belts 12 in. wide. The motors are squirrel cage, and the pumps are started with the delivery valve closed, but without any bye-passing arrangement.

The efficiency of the pumps on test is shown in Table J2.

TABLE J2

No	Motor Input, H P	Motor, R P M	Pump, R P M	Water Delivered, Gallons per Minute	Static Head, Feet	Pumping Head, Feet	Efficiency Overall	Efficiency Pump
1	87 15	720	2,885	120 5	1,228	1 262	52 9	60 2
2	31 5	720	1,920	141 3	255	368	50 0	62 75

The effect of the friction in the long suction pipe is evident in No. 2 Test, where the actual head is only 255 ft.

An automatic device actuated by a float is arranged for stopping the pump when the water level in the sump has been lowered to a determined point to prevent air running into the suction, a wire connection from the float actuates a relay switch and cuts out the motor by tripping the automatic switch. The general arrangement of the pumps working in the U tube is believed to be novel, and in any case it presents an economical and mechanical method of providing duplicate pumps for varying duties.

Comparison : Ram and Centrifugal Types.—The Ram pump when in best working order is more efficient than a centrifugal, especially in small sizes, but its efficiency may be greatly influenced by the adjustment of the packing, glands, &c. For a duty of, say, 500—600 gallons per minute and 600 ft. head the capital cost of the ram pump would be about twice as high

as that of the centrifugal, or perhaps even higher, depending on the switching and control arrangements called for.

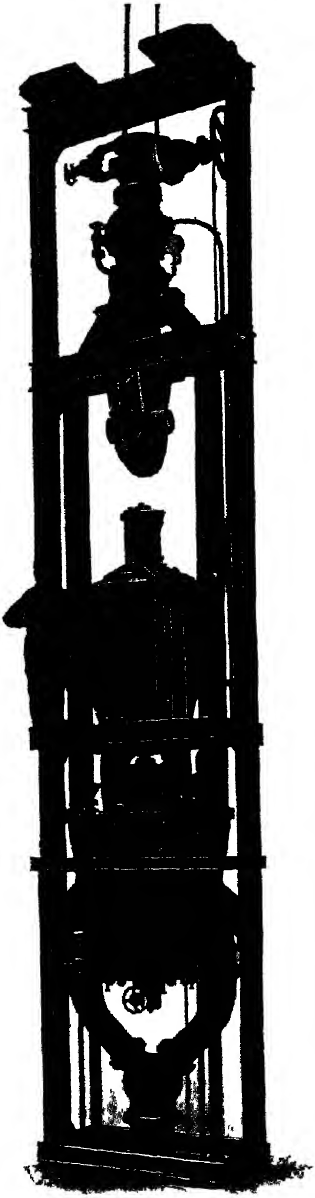


FIG. J7.—Sulzer's sinking pump.

The ram pump would also, on account of its dimensions and its working strains, require a larger house and considerably more foundations, so that the cost of housing and fixing would be two or three times as great as that of a centrifugal. These items, which influence the capital cost, increase the standing charges and consequently discount the advantage the ram type has in respect of cost of power. These points are of especial importance where the hours of running are short, and for stand-by plant.

With regard to the question of flexibility of centrifugal pumps in comparison with piston pumps, it is obvious that the advantage is with the latter class. A centrifugal pump ought to be run as nearly as possible under the conditions for which it was built.

Sinking Pumps.—The question of Sinking Pumps stands apart, as in their case ease in handling and space occupied are of more importance than other advantages. The direct-coupled vertical spindle centrifugal is a particularly happy solution of the problem. The amount of grit and slime in the water may cut the pump, but in many shafts this is less important than the space occupied by elaborate means for preventing

it. In sinking a large shaft Mr G G Hann (Proc. S. Wales Inst. Eng, Vol. XXVII., p. 61) experienced this difficulty and recommends a low-lift compressed air pump to deliver the water into settling tanks, from which the high-lift centrifugal pump throws it to the surface. The wear in these high-lift pumps is evident in loss of efficiency, and in some types by their getting out of balance. The latter defect is met if the balancing arrangement is external to the water-carrying parts of the pump, as in the case of Boving's oil-balanced footstep.

Sinking pumps are generally arranged in a steel framework, as shown in Fig. 37, which is slung from a winch at the shaft-top and can be adjusted at will. Sometimes two pumps are mounted in one frame, as in the case of the Sulzer pumps used for sinking the Bedwas Pit, where two pumps to deliver 20,000 gallons against 540 ft head are so arranged and driven by totally enclosed motors, the pumps, motors, pipes, and water, in working order, weighing about 30 tons (Proc. S Wales Inst. Eng, Vol. XXVII., p. 62).

Sometimes for unwatering an inclined shaft and for dip pumps it is convenient to arrange the pump and motor on wheels running upon rails in the shaft. In such cases, unless the pump is mounted on such a carriage that its shaft is horizontal, the arrangement of the bearings requires special attention, as on an incline ordinary ring lubrication will not work owing to the oil rings touching the sides of the grooves. Chains will work better than rings, but require more than usual attention, and it is better to keep the pump horizontal if possible.

Tresavean Unwatering.—An important instance of unwatering a mine was fully described by Mr. Brackenbury in a paper read in January, 1912, before the Institute of Mining and Metallurgy in connection with the Tresavean Mine, where serious obstacles and difficulties were met with, but eventually overcome. The engineers required some faith to start such a scheme in Cornwall, where, due to the failure of centrifugal pumping plant previously, sometimes to causes quite outside the pump itself, the system had been discredited. The unwatering of the mine was effected with six centrifugal pumps

There are six shafts. Two of them have an inclination of about 45°; in each of these shafts a Sulzer high-lift centrifugal pump, direct coupled to an A. E. G. motor and erected on a carriage, which was lowered into the mine as the water was pumped out, was employed. The pumps were rated at 4,000 gallons per minute at 394 ft. head and were of the one-stage type. The motors were operated at 3,000 volts, 50 cycles, and rated at 750 h.p. at 1,485 r.p.m. The pump efficiency was 77 per cent. and the combined efficiency of these sets was 70 per cent.

The four other shafts were vertical, and in them sinking pumps, which were slung from the surface, were employed. Two had a duty of 1,000 gallons per minute at 680 ft. head, with motors of 315 h.p. at 1,480 r.p.m. These pumps were of the three-stage type with an efficiency of 73 per cent.; the equipment had a combined efficiency of 67·75 per cent.

The other two shafts were equipped with five-stage pumps to handle 1,000 gallons per minute against 540 ft. head direct coupled to motors of 250 h.p. at 1,480 r.p.m. The efficiency of these pumps was 77 per cent.; the equipment had a combined efficiency of 71·5 per cent.

In order to facilitate operations the sinking pumps were specially designed, so that in the early stages of unwatering only one impeller would be in use and at a later stage two new impellers would be put into the pump casing. By this means the pumps will raise nearly 50 per cent. of their normal output at the increased head.

A complete power station had to be specially built in connection with the unwatering scheme containing three 1,140 k.w. turbo-generators.

CHAPTER X

ROLLING MILLS

The application of electric driving to Rolling Mills has gone hand in hand with the better utilisation of the waste heat from the blast furnaces. Some 45 per cent. of the gas from the blast furnaces is available for power purposes after the heating stoves, blowing engines, and other demands have been met, so that where rolling mills are worked in connection with blast furnaces the conditions are eminently favourable for the generation and use of electric power. A list of German Iron and Steel Works published in "*Glückauf*" by Dr. Jüngst in December last mentions seven works whose aggregate output of electricity is upwards of 100,000,000 units per annum.

To keep the generating plant at full load is essential for low cost of production; hence everything must be done which will reduce the fluctuations of the load without unduly piling up the capital and stand-by charges in respect of the equalising plant, or putting weak links in the chain, which may fail and decrease the output of the mill. No economies when running will atone for the losses due to breakdown and stoppage of the mill.

Types of Rolling Mills.—There are various classes of rolling mill, such as Bloom, Ingot, Sheet, Rail, Tyre, all of which take their name from the material handled. There are also two main types into which the classes can be grouped, which are of more importance when discussing methods of driving. These are—

The Continuous mill, and the Reversing mill.

In the former the rolls always run in one direction and are arranged in frames three or four high, the adjacent rolls of course running in opposite directions, so that the material to

be rolled can be passed between a pair suitable to give the direction required. If a light section or rod is being rolled it can be easily lifted from the bottom roll or floor level to the upper side of the roll to pass it back, but when heavy sections or ingots are being rolled the necessary lifting or tilting tables form a most elaborate and costly part of the equipment.

In the Reversing mill the section to be rolled always remains at the same level, the different passes being effected by reversing the direction of rotation of the rolls.

The live rolls in the floor which feed the material into the rolling mill have to be reversed as in the case of a continuous mill, but as they are always on the ground level and do not require elevating or tilting the operating gear is much more simple.

The question as to whether the mill must be of the continuous running or the reversing type will be decided by the management, who may have predilections in favour of one type or the other, or one of the types may be more suitable for the particular work in view.

The electrical equipment of the continuous type is the more simple, as the fly-wheel can be direct-coupled to the motor shaft, and the only elaboration will be in the starting gear, which must be heavy enough to carry the high current necessary to overcome the inertia with reasonable speed.

The electrical equipment is therefore of the most simple, and so least costly, type, but the cost of the three-high rolling mill with tilting or lifting tables and necessary auxiliary machinery required to work them will be higher than that of a two-high reversing mill, which needs no such auxiliaries.

The reversing mill presents just the opposite characteristics, as in order to facilitate reversing quickly the fly-wheel effect on the roll shaft must be kept down to the lowest possible limit, and to take care of the fluctuations of the load the fly-wheel effect must be inserted between the motors and the line. This is done by a fly-wheel motor-generator set or equaliser of some type, which adds to the expense of the electrical equipment, and the roll motor must be large enough to give the full power for the rolls, and so heavier than the motor for the continuous mill, which only supplies part of the energy, the other part

being given out by the fly-wheel. The two-high reversing mill complete with electrical driving gear will therefore cost about as much as the three-high continuous mill with its more simple driving gear; but it is a much more flexible machine, as the speed can be varied to suit the different passes, with beneficial results on the output.

To sum up the question: The fluctuations on a continuous mill must be taken up by a fly-wheel on the rolling motor, while in a reversing mill they are taken care of by fly-wheel effect in a motor-generator set or equivalent means.

Taking the matter a stage further, and considering the effect on the line or power station, the maximum demand will be greater in the case of a continuous mill than with a reversing mill. This will affect the cost of energy and the economical working of the power station.

The cost of power in a mill is not a large percentage of the cost of production, and sometimes it has been considered that the saving due to electrical driving is not worth the risk of failure in the more complicated machinery. Practical results have shown that not only is there a saving in cost of power, but there is also an important gain due to the increased output from the mill. This increase is due to the more even turning moment, which decreases the number of breakages, and to the more regular speed of the motor, which does not slow up as the load comes on to it. In a reversing mill the speed can be varied at will, and in a continuous mill with three-phase motors two or three speeds are sometimes provided, so that the last passes, which are longer and may take less power than the earlier passes, can be run at a higher speed.

The power called for varies within wide limits in the same mill. Normally, owing to the irregularity of the surface, the work that can be put into the material is not so great in the first few passes as in the succeeding passes, and in the last passes, if they are finishing passes, for any particular section less work must be put into the material, just as in hammering the finishing touches are light ones. Generally, however, it may be taken that every time a bar passes it becomes longer, and as a rule the power called for is less as the section becomes smaller, but the hardening of the metal due to cooling, and the

shape of the section, may cause as heavy a call for power in the later passes as in the earlier ones.

A most elaborate investigation of the power taken in rolling mills was made by Dr. J. Puppe in Germany. The mill-owners, when they saw what was in hand, so appreciated the value of the investigation that they threw themselves heartily into it and placed their mills at Dr. Puppe's disposal for the purpose of the test, doing all they could to facilitate the research. The result is a monumental work entitled "Experimental Investigations on the Power Required to Drive Rolling Mills," which is full of interesting details. The labour spent on the calculations must have been immense.

A few characteristic values for the kilowatt hours per ton rolled obtained on tests from reversing mills were given by Mr. C. A. Ablett in his paper read at the meeting of the Iron and Steel Institute, September, 1909, and are reproduced in Table K1.

TABLE K1.

	Kilowatt Hours per Ton
$4\frac{1}{2}$ in. × $4\frac{1}{2}$ in. billets from 2·5-ton ingots. Output, 53 tons per hour	22·5
6 in. × 6 in. blooms from 2·5-ton ingots. Output, 63 tons per hour	17·5
8 in. × 8 in. blooms from 2·5-ton ingots. Output, 80 tons per hour	13·0
12 in. × $9\frac{1}{2}$ in. blooms from 7-ton ingots, measuring $34\frac{1}{2}$ in. × 25 in. Output, 65 tons per hour	11·2
32 in. × 9 in. slabs from 6-ton ingots, measuring 36 in. × $19\frac{1}{2}$ in. Output, 40 tons per hour	4·3
32 in. × 5 in. slabs from 6-ton ingots, measuring 36 in. × $19\frac{1}{2}$ in. Output, 40 tons per hour	5·8
Flange rails, 100 lbs. per yard, from 2-ton ingots. Output, 30 tons per hour ..	48·0
Beams, 120 lbs. per yard, from 1·5-ton ingots	36·0
Channels, 92 lbs. per yard, from 1·5-ton ingots	37·0

The Mechanics of the Problem are, to a great extent, similar to those of the electrical winder. The total power required is made up of the power necessary to accelerate the masses, the power necessary for rolling, and the power necessary for overcoming the friction.

The power required for rolling depends upon—(1) The temperature of the metal; (2) the quality of the metal; (3) the section to be rolled.

In a continuous mill, when no speed regulation is required, the fly-wheel effect can be applied on the roll shaft and must be sufficient to level out the fluctuations in power during the various passes. In a merchant mill where several stands of rolls are coupled together the material may be passing through different rolls at the same time, which helps to average the demand for power.

In a reversing mill the problem is even more akin to that of a winding engine. For each pass the following sequence of operations has to be gone through:—

Revolving masses started and accelerated;
Friction overcome;
Material rolled;
Revolving masses retarded and stopped.

The amount of energy for accelerating the masses is very large, and may be as much as 17 per cent. of the total energy required. In the case of electrically driven reversing mills the energy thus expended may be largely returned, whereas in a steam driven mill this energy is lost.

Friction Losses.—Friction losses are highly important owing to the relatively short time during which rolling is actually in progress. Rope driving was often employed as it enabled a high-speed motor to be used, and the ropes kept the vibration of the rolls off the motor. The rope drive may, however, be responsible for a loss of 10 per cent. of the normal full-load power, and at constant speed this loss remains the same, no matter whether the motor is running full or only lightly loaded.

In some cases one motor has been used to drive two sets of rolls, being direct coupled to one set and roped to the second.

Such arrangements may be dictated by convenience and the difference in cost between one motor and two, but the running losses are so important that they must be considered.

Mr. C. A. Ablett, in his paper read before the Institute of Electrical Engineers in January, 1912, Vol. XLVIII., p. 621, shows that the loss in rope driving may amount to 4,200 units a week for a 450 h.p. motor in a tin-plate mill. This at ·5*d* per unit amounts to £437 10*s*. per annum, and would soon absorb the difference in price between a high-speed motor for rope driving and low-speed motor for direct coupling to the rolls, or between the cost of one motor and two for the same work. He cited comparative figures for Sheet Mills which took 135 B.T.U. per ton rolled when rope driven and 85 to 90 B.T.U. when direct coupled.

The vibration caused by the rolls is very great, and would soon have a deleterious effect on the motor if it were rigidly coupled to them. An elastic coupling should therefore always be inserted between the motor and the rolls. The conditions under which rolling mills operate are not such as induce nice fitting and sweet running. With steam-driven rolls friction losses are difficult to measure, but with the ready means for taking electrical measurements the author expects that the matter will have attention, and the result will be less friction and better upkeep, with fewer failures of the roll necks.

The Electrical Problem.—The essential points in which the working differs from the winding engine problem are .—

(1) There is no fixed time per operation as with a winding engine, as the time taken per pass becomes longer after each consecutive pass on account of the elongation of the metal. By controlling the speed of the motor this difference per pass may be, to some extent, minimised.

(2) The acceleration in the case of reversing rolls is much more rapid.

(3) The load is extremely fluctuating—in fact, variations from 0 to 4,000 h.p. take place in one second, and complete reversals in four seconds are common ; the load also varies in magnitude from pass to pass.

The output of the motor is equal to the root-mean-square

torque multiplied by the angular velocity, but as this torque varies from pass to pass the root-mean-square value over the complete number of passes must be calculated. As a basis for determining the acceleration and retardation rates, it may be assumed that the maximum torque of the motor must not be more than twice the average torque.

The continuous mill running at constant speed presents no serious difficulties. When speed regulation is necessary a Kramer or Scherbius regulating set working in conjunction with the main induction motor may be used (*vide* p 208, *ante*). One advantage in this method of regulating is that on account of the phase-correcting properties of the commutator motor the output of the main motor is proportionately increased.

Control.—The reversing mill cannot be worked directly from the supply ; some form of equaliser becomes necessary. The Ward-Leonard-Ilgner control has proved the most economical and suitable, and almost all modern plants are carried out on that system or modifications of it. By means of the Ward-Leonard-Ilgner control the fluctuations of the supply are materially reduced, as by means of a slip-regulator the fly-wheel stores energy during the rest period or interval between rollings, and gives out the surplus energy during the rolling period (*vide* p. 179, *ante*). The shorter the interval the higher the output of the rolling motor, but the smaller the percentage fluctuation of power for a given fly-wheel. The longer the interval the smaller the rating of the motor, but the larger will be the fluctuation for a given fly-wheel.

The simple Ward-Leonard control does not provide a large starting torque, and, as in reversing mills where the motor has to be brought up to full speed in the space of a second, large starting torques are essential, various modifications have been introduced to obtain the necessary torque without sacrificing the inherent qualities of the Ward-Leonard control, among which may be cited the Siemens series-parallel control and the A. E. G. patent exciter.

The Krämer and Crepelet systems (*vide* p. 166, *ante*) have also been employed, and a new application of the battery equaliser with a special form of rotary converter.

Battery Equaliser.—A new method of employing batteries has been evolved by Mr. J. C. Woodbridge in America and described by him (Institute of American Electrical Engineers, June, 1909). He combines the use of a split-pole rotary converter connected to the line on its alternating current side and directly across the terminals of a battery on its continuous current side, with an automatic regulator operated by the line current, which determines whether the rotary shall work direct, and charge the battery or shall be worked by the battery discharge as an inverted rotary and feed the line.

In a split-pole converter each pole of the field magnets is divided and energised by two separate circuits ; one is held at constant potential, while the potential on the other can be varied and reversed. The effect of the change in field strength is negligible on the three-phase side of the machine, but strengthens or weakens the voltage on the continuous current side. Hence, if the line current operates a relay which works the regulating and reversing switch on the variable field circuit, the split-pole converter will automatically and promptly regulate the pressure on the three-phase line without the interposition of a booster

Skinningrove.—A very fine Reversing Rolling Mill has been equipped by Messrs. Siemens Brothers for the Skinningrove Iron Co. at their works in Yorkshire. A Siemens-Ilgner electrical equipment is used for driving this mill. The control is on the usual Ward-Leonard system, but an additional feature is the series-parallel switch in the generator circuit. Fig. K1 shows a diagram of the machines and connections.

The mill consists of a 36-in. cogging mill, a 36-in. roughing mill, and a 36-in. finishing mill, all arranged in line and driven by one reversing mill motor. The plant is designed for rolling down ingots weighing from 2 to 4 tons into rails, beams, angles, &c , and to give an output of about 30 tons per hour. If it is desired at a later date to increase the output a second motor could be put down at the opposite end of the mill to the present motor to drive the roughing and finishing mills separately from the cogging mill ; the spindles at present coupling the cogging mill to the finishing mill would then be removed.

The reversing motor is a double armature machine, capable of giving a normal turning moment of 312 foot-tons and a maximum turning moment of 475 foot-tons at all speeds between 0 and 60 r.p.m., with the armature of the variable voltage dynamos connected in series. At 60 r.p.m. the outputs corresponding to the above turning moments are 8,000 and 12,000 b.h.p. respectively. To enable larger turning moments to be obtained during the first few passes in the cogging mill the two armatures of the variable voltage dynamos can be put in parallel, when a normal turning moment of 425 foot-tons and a maximum turning moment of 520 foot-tons can be obtained at all speeds between 0 and 30 r.p.m.

To provide for the finishing passes when low torques are required at high speeds to get the material quickly through the rolls before it has time to cool, by reducing its field current the speed of the motor can be increased up to 120 r.p.m., the turning moment being gradually reduced as the speed increases to a value of 137 foot-tons at 120 r.p.m. The motor can be started up from standstill to 60 r.p.m. in one second, so that a remarkably rapid reversal can be obtained. In order to do this the motors were designed with the minimum fly-wheel effect, and in order to keep down the diameter of the armature each motor was built with two armatures coupled together and carried in two bearings. The motors are provided with forced draught ventilation.

The fly-wheel motor-generator set consists of a pair of fly-wheels mounted side by side and supported by two bearings, each wheel weighing 23 tons. This arrangement was adopted to avoid difficulty in transporting a single solid wheel weighing 46 tons. The fly-wheels are 12 ft. 8 in. in diameter, the maximum speed being 475 r.p.m., or equivalent to a peripheral speed of 19,000 ft. per minute ; the stored energy at this speed is 178,000 h.p. seconds.

This fly-wheel set is provided with the usual forced lubrication and other precautionary measures to ensure reliable running. The fly-wheels are coupled to the electrical machines by means of a steel needle coupling consisting of two discs about 4 ft. in diameter, one of which is keyed to each of the shafts. The discs are connected together by forty-four nickel-

steel rods, which are rigidly bolted to one disc and rest in spherical seatings in the other disc. The coupling is designed

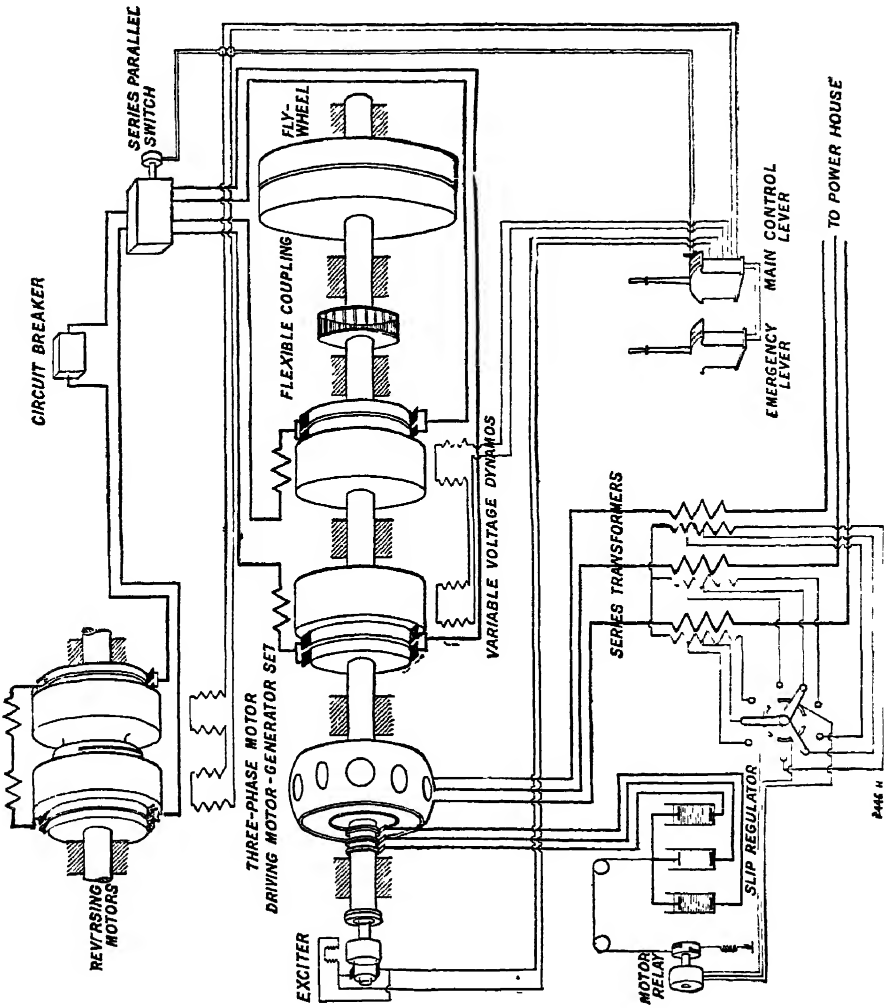


Fig 81 Skinningrove reversing mill

for transmitting powers of about 12,000 h.p. at speeds of from 380 to 475 r.p.m.

The two dynamos are placed next to the fly-wheels, and the three-phase motor driving the motor-generator set is placed at the opposite end to the fly-wheels. This arrangement was adopted because at times the fly-wheels have to give out

12,000 h p. to the dynamos, and it is desirable to transmit this large power through as short a length of shaft as possible. The three-phase motor, on the other hand, does not give more than 1,825 h.p. to the dynamos or the fly-wheels, as the case may be. These dynamos can be connected in parallel or in series according as the mill motor is required to give high turning moment at low speed or low turning moment at high speed. They are provided with a double commutator, interpoles, and compensating winding. On account of the high speed no forced draught ventilation is required; the bearings are of the ordinary oil-ring type.

The three-phase motor has a normal output of 1,825 h.p., and is wound for 40 cycles and 1,650 volts. A small exciter is coupled to the three-phase motor end of the motor-generator set in order to supply the excitation current for the fields of the mill motor and the dynamos.

With this fly-wheel set an output to the motors up to 12,000 h.p. during a pass lasting a few seconds can be secured, with an approximately steady power from the supply of 1,825 h p. To enable the fly-wheel to give out this energy the usual slip regulator is provided to reduce the speed 20 per cent , thus rendering 36 per cent. of the stored energy of the fly-wheel, or 64,000 h.p. seconds.

The control gear is placed on the driver's platform; the lever on the right is the main control lever and that on the left the emergency lever. The first controls the direction of rotation and the speed of the mill motor by varying the resistance in the field circuits of the dynamos and of the reversing motor. In the middle position the mill is at a standstill. As the lever is moved forwards from the middle point the mill motor increases in speed in one direction, and as it is moved backwards from the middle point the mill motor increases in speed in the other direction.

The speed of the motors is controlled by altering the strength both of the generator field and of the motor field. Up to speeds of 60 r.p.m. the motor field is not touched, but for speeds above 60 to 120 r.p.m. the motor fields are weakened.

A full description of this plant appeared in *Engineering,*

29th September, 1911; the proprietors have been kind enough to loan the block of Fig. K1, showing the connections.

Dorman, Long.—The electrically driven Reversing Rolling Mill at the works of Messrs. Dorman, Long & Co., Middleborough is by Messrs the British Thomson-Houston Co, Ltd.

The cogging mill is designed to reduce mild steel ingots 12 in. square and weighing about 1 ton each to billets 3 in. square at the rate of about 15 tons per hour. The rolls are connected by a special coupling, designed to avoid end thrust, to a motor with a continuous rating of 1,200 b.h.p. at 70 r.p m., which has a maximum torque corresponding to an output of 3,600 b.h.p. The motor is fitted with commutator poles and special compound field winding, as will be described more fully in connection with the Julienhutte equipment (p. 266, *post*) The mill motor can be reversed from normal full speed of 70 r p.m. in one direction to normal full speed in the opposite direction in about four seconds.

The current is supplied from a fly-wheel motor-generator set, the motor in which is of the three-phase type, 950 b h.p. at any speed from 400 to 480 r.p m., 2,750 volts, 40 cycles This motor can exert two-and-a-half times normal torque The generator is 1,000 k.w. normal rating at 400 volts, and will carry up to 9,000 amps without sparking. The fly-wheel weighs 30 tons, and has a peripheral speed of 18 600 ft per minute. In case of emergency it can be brought to rest in less than two minutes by a brake provided with water-cooled cast-iron brake blocks.

For starting the motor generator set a barring gear of the self-releasing type driven by a 15 h p. compound-wound variable speed motor is mounted on an extension of the fly-wheel shaft, by means of which the fly-wheel set can be started with considerably less than the normal full load current. The barring gear motor is supplied with current from an exciter set giving 220 volts: 100 amps. is required to set the gear in motion, and 20 amps. will keep the fly-wheel running at 30 r.p.m.

The special three-unit exciter set is driven by a 75 h.p., 440 volt, three-phase motor.

The control of the mill motor is entirely effected by the regu-

lation and reversal of the current in the shunt winding of the generator field, which is handled by a controller of the tramway type fixed on the driver's platform.

Hickman, Ltd.—A large electrically driven Reversing Rolling Mill equipment has been supplied by the Electric Construction Co., Ltd., to Messrs. Alfred Hickman, Ltd., Bilston. It consists of a 30 in. cogging mill, which reduces 2½-ton ingots to blooms of 4½ in. to 6 in. section, and a 24 in. bar mill with two sets of housings and rolls, which is built for rolling sheet bars, billets, &c.

This is the only equipment in which variable voltage generators and motors work at plus or minus 1,000 volts pressure and in which the mills are driven by single motors. Continental and American practice is in favour of driving the mills by double motors, as it is claimed that they are more handy and that the reversing is quicker.

In this case the guaranteed time of reversal for each mill motor was not to exceed six seconds from maximum speed in one direction to the maximum speed in the opposite direction. In practice this has been easily accomplished.

The cogging mill motor is connected to the rolls through a 2 to 1 double-helical gearing. The motor will develop 4,800 b.h.p. at 1,000 volts for five-second periods six times per minute as a rolling load, and a maximum load of 9,600 b.h.p. for two-second periods once every hour. The speed of the motor at which the output is measured is 120 r.p.m. The efficiency of the motor is 94½ per cent. at full load.

The bar mill motor is coupled directly to the rolls, and will develop 6,000 b.h.p. for five-second periods six times per minute and a maximum load of 12,000 b.h.p. for two seconds once an hour. The speed of the motor is 120 r.p.m. This motor complies with the same reversing and efficiency tests as the cogging mill motor.

This Fly-wheel Motor Generator Set has occupied a prominent position in the Law Courts in connection with the fight over the Ilgner patents. The set consists of one motor, two fly-wheels, and two generators, each generator being in direct electrical connection with its own mill motor. Power is supplied

from the central station to the motor of the fly-wheel set at 460—500 volts continuous current. The motor is shunt wound and designed to develop 2,000 b.h p. on continuous load. The

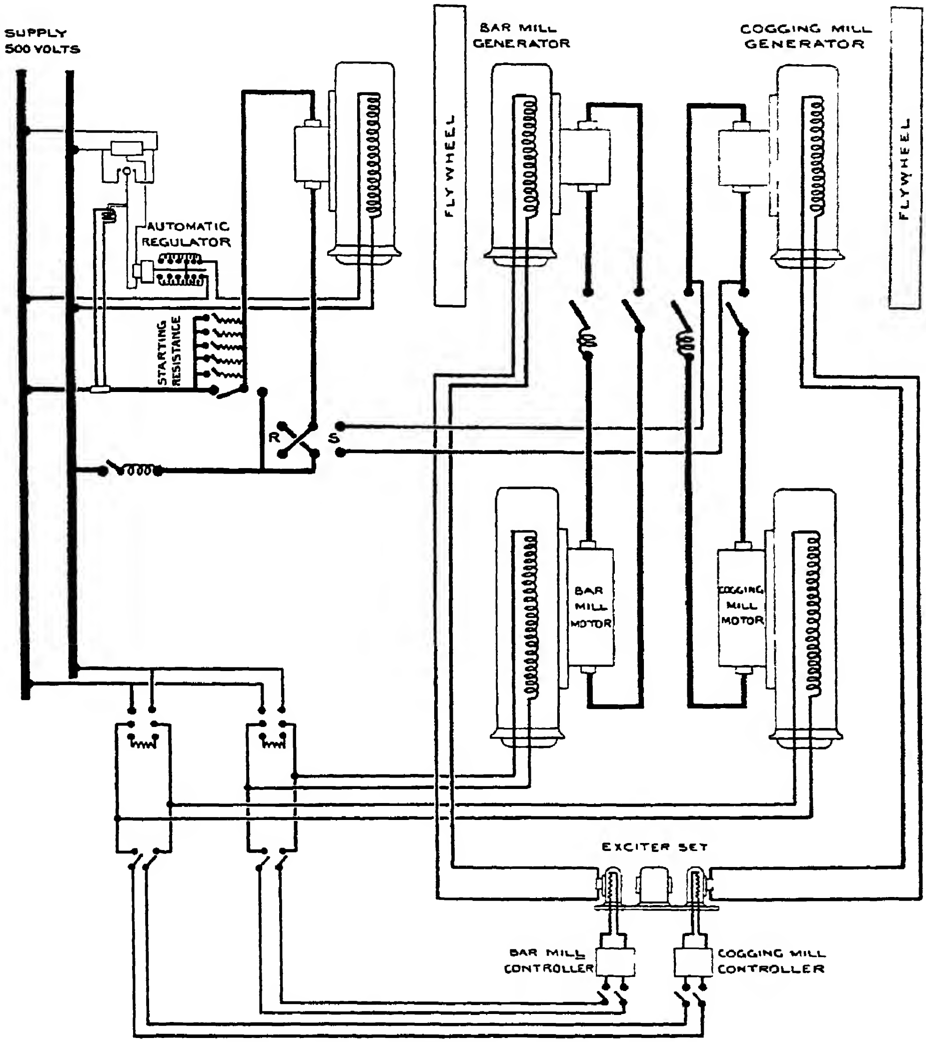


FIG K2 —Hickman's reversing mill.

magnetic circuit of the motor is specially laminated for the sake of speed control. The generators are both separately excited. The efficiency of each of the three machines is 94½ per cent. at full load.

The two fly-wheels are each 14 ft. in diameter and weigh 28 tons, with a normal peripheral speed of about 15,400 ft. per minute. They are each built up of three separate steel castings; the maximum speed of the fly-wheel set is 350 r.p.m., which is decreased by an automatic regulator to 290 r.p.m. To obtain this variation in speed the motor of the fly-wheel set has a resistance in its shunt field-magnet circuit, which is varied by an automatic regulator operated by the main current; the regulator is set to come into operation when the current input rises above or falls below a pre-determined value and equalises the load on the generating station to within 20 per cent. of the average load.

The control is on a system similar to the Ward-Leonard, the voltage variation of each generator being obtained by the operation of a single controller situated on the corresponding mill platform. This controller varies the field excitation of a small motor-driven exciter, which in turn varies the 460 volts excitation of the main generator. The speed of the rolling motor therefore depends upon the voltage applied to its armature. The master controller does not have to handle current greater than 1 amp.; hence manipulation is very easy, and there is an entire absence of arcing. With this system of control only a small amount of energy is lost in reversing the mill, as the energy expended in accelerating the rotating masses is largely returned in the form of electrical energy when the speed is decreased. Indicators to show the speed of the rolls and of the fly-wheel set are mounted on each mill platform, and the equipment includes the usual circuit breakers and auxiliary devices. The electrical connections of the scheme are shown in Fig. K2.

Algoma.—One of the newest reversing Rolling Mill equipments is that of the Algoma Steel Co. in Ontario, which was started in December, 1911.

The bloom mill is designed to handle 75 tons of 20 in. by 20 in. ingots per hour and to turn them into billets 8 in. by 8 in. in fifteen passes. The rolls are direct-driven by two 600-volt continuous current motors on the same shaft. A heavy thrust bearing is inserted between the rolls and the motor shaft. Each

of the motors has a normal rating of 2,000 h p. at 75 r p m.; their 600-volt armatures are connected in series. They have a maximum rating of two-and-a-half times the normal, giving a combined maximum of 10,000 h p available for short intervals.

The motor is constructed of the double unit type, in accordance with the usual practice for a rolling mill where frequent and rapid reversals are required and it is necessary to keep down the momentum of the parts to the lowest possible point. The motors are provided with compensating windings, and their fields are each separately excited from a 250-volt circuit with a regulating resistance in each, so that the load on the two motors may be equally divided. The direction and speed of rotation is controlled by varying the direction and amount of the voltage across the armatures on the usual Ward-Leonard system. The design has so far fulfilled expectations that twenty-two reversals have been made in one minute with 75 r.p m maximum speed

A Fly-wheel Motor Generator set supplies the current to drive the motors. The induction motor in this set is rated at 1,800 h p., 2,200 volts, 25 cycles, at 375 r.p m. synchronous speed.

The fly-wheel is 12 ft. in diameter and weighs 66 tons . it is made of cast steel in three sections.

The continuous current generator is also made in two parts, each having a normal rating of 2,250 h p on 600 volts at 375 r.p m. The armatures are connected in series, and the machines are capable of carrying an overload of two-and-a-half times the normal. The generators are of the compensated interpole type , the magnetic circuit is entirely of laminated steel, so that it may respond quickly to the desired changes in strength called for by the rapid operation of the rolls.

The bearings are provided with forced lubrication, and the oil pump is started in the usual way to lift the shaft and bearings out of contact and to establish the oil film before the current is switched on. The starter which is used to bring the set up to full speed is of the liquid resistance type and calculated to have sufficient capacity to absorb the total kinetic energy of the fly-wheel set at full speed.

The motor-generator set is provided with an automatic

slip-regulator, which controls the recuperative power of the set to suit the work in hand.

Julienhutte.—A fine Reversing Rolling Mill equipment has been put up by the A. E. G. Co., of Berlin, at the Julienhutte Works, Gleiwitz.

The mill reduces ingots about 22 in. square and weighing 4·5 tons to billets 8 in. or 3 in. square, and will handle nine or ten such ingots per hour, the number of passes being twenty to thirty respectively.

The rolls, which are 43 in. in diameter, are direct-coupled to the motors, a heavy thrust bearing being provided to protect the motors from the effects of broken rolls.

The motor consists of two units erected on one bed-plate. They are capable of a continuous output of 3,600 h p. and a maximum output of 8,100 h.p. The speed with full field is 65 r.p.m. and the maximum speed with a weakened field 120 r.p.m The maximum turning moment is 470 foot-tons. The voltage across each armature is 550, giving 1,100 volts across the complete motor.

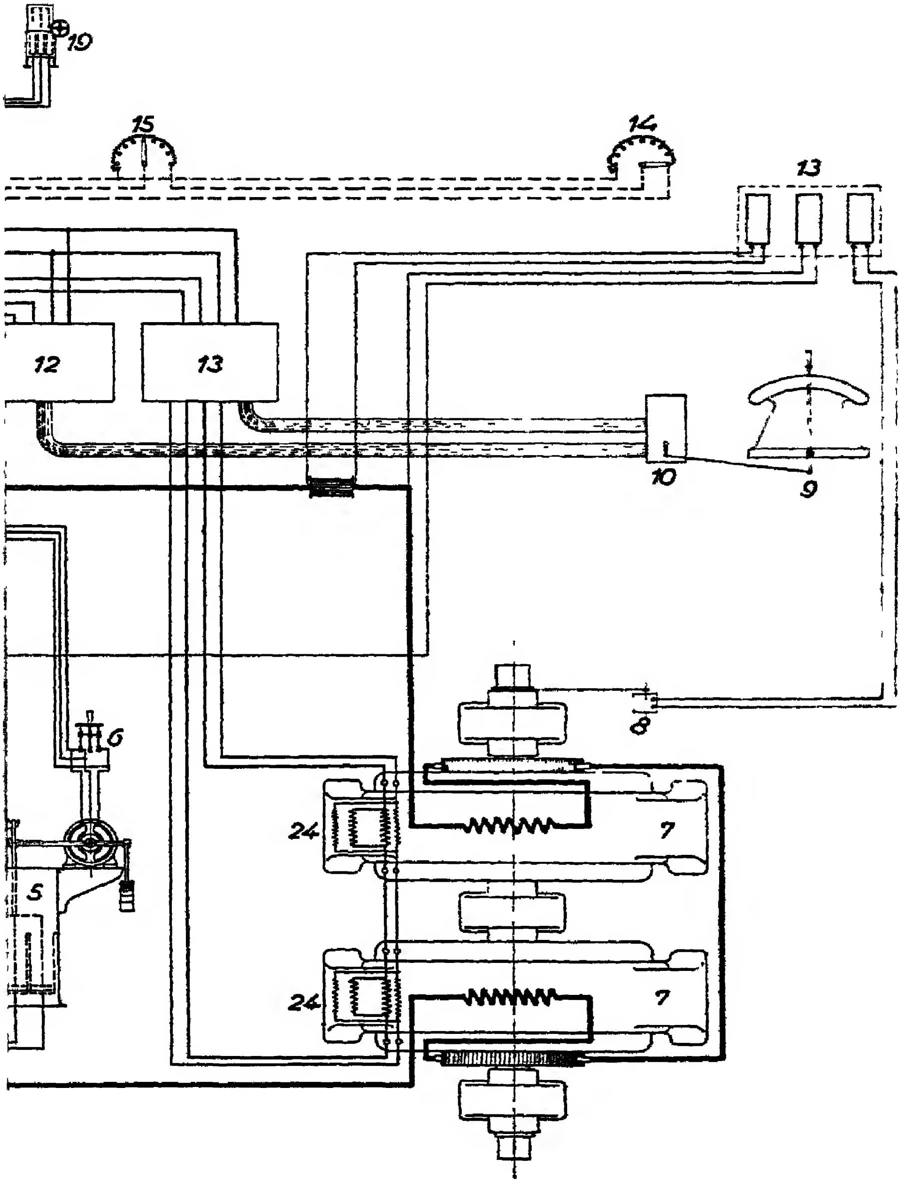
The Fly-wheel Motor-Generator set consists of two generators, two fly-wheels, and two motors. The motors are three-phase, 6,000 volts, with a maximum speed of 375 r.p.m. The continuous current generators are each wound for 650 volts, and, as will be noted from the diagram (Fig. K3), are connected in series and to the rolling mill motor, the two halves of which are also in series. The rated continuous capacity of each motor is 1,000 h.p. Each fly-wheel weighs 24 tons.

An important point in this successful installation is the compound arrangement for exciting the motors, which is arranged according to the A. E. G. Co.'s patents.

It will be seen from the diagram that the field of the rolling mill motors and of the generators is due to three different windings :—

(*a*) The compensating windings, which are all in series ;

(*b*) and (*c*) Separately excited windings, the energy for which is taken from one or other of the two dynamos (Nos. 17 and 18) on the motor-generator exciter set driven by motor No. 16.



witch.
ion.
r.
no.
dynamo.

19. Starter.
20. Oil switch.
21. Disconnectors.
22. Excess pressure protector.
23. Earth testing device.
24. Diverting resistance.

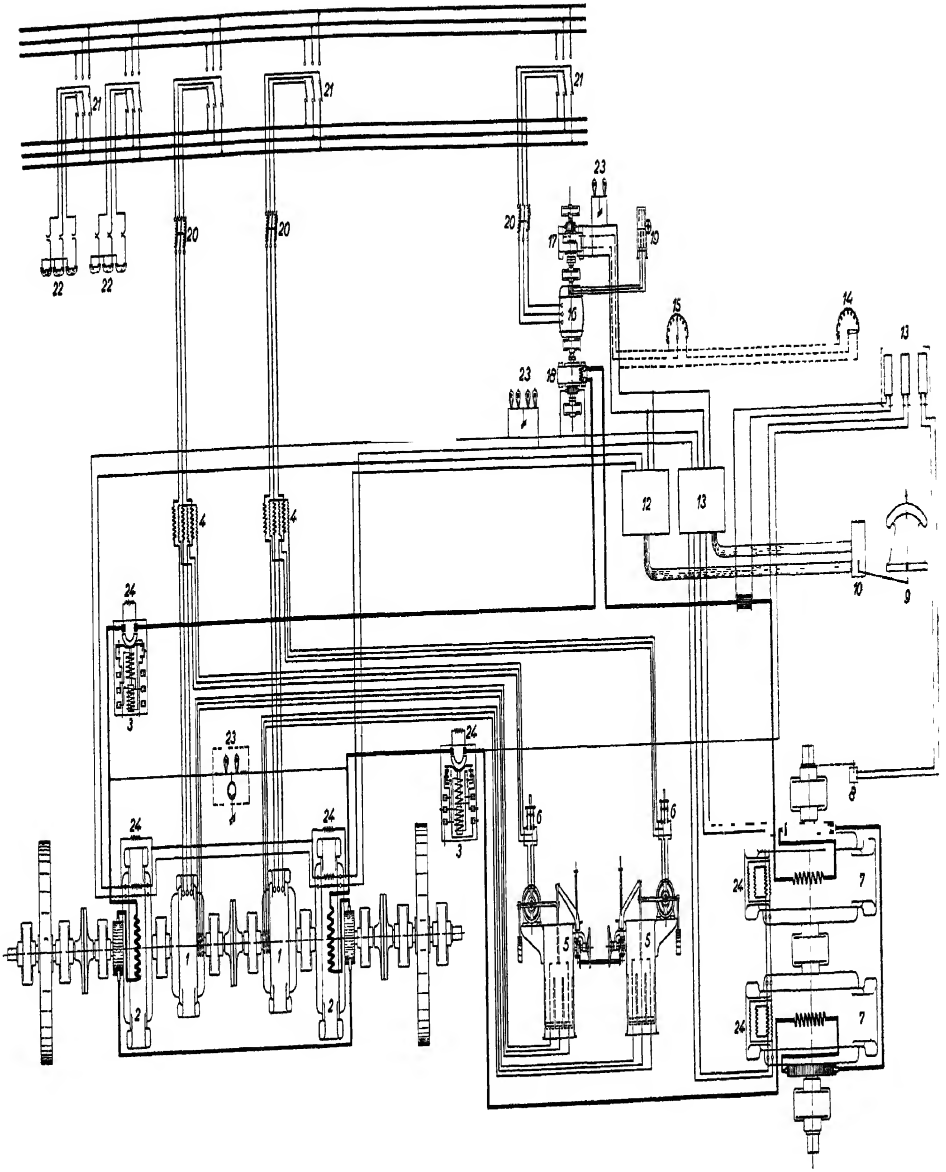


FIG K3.—Julienhutte reversing rolling mill

1. Ilgner motor.
2. Starting dynamos.
3. Overload circuit breaker.
4. Transformer.
5. Starting and slip regulating resistance.
6. Short-circuiting switch.
7. Reversing motor.
8. Electrical speed indicator.
9. Control lever.
10. Controller.
11. Resistance for motor field regulation.
12. Resistance for dynamo field regulation.
13. Switch desk
14. Emergency switch.
15. Shunt regulation
16. Exciter motor
17. Exciter dynamo.
18. Compounding dynamo
19. Starter
20. Oil switch.
21. Disconnectors
22. Excess pressure protector
23. Earth testing device
24. Diverting resistance

To face page 266.

One of these two dynamos (No. 17) is an ordinary continuous current compound-wound machine, which supplies the main fields of the mill motors (No. 7) and of the generators (No. 2) of the fly-wheel set. The other dynamo (No. 18) is a special series machine whose field is solely due to the main current; this machine is called the auxiliary exciter, and the fields energised by it are called the auxiliary fields. It has a weakly saturated field, so that its output is directly proportional to the current in the main circuit, but reverses in polarity at each reversal of the main circuit.

The auxiliary field on the rolling mill motor is always kept in the same sense as the main field of the motor: the compounding effect, therefore, of the auxiliary field is to increase the torque of the motor; hence the auxiliary field of the motor has to be reversed at each reversal of the main circuit.

The auxiliary exciter also supplies the auxiliary field of the main generator, which is compounded to always oppose the main field; hence this circuit has not to be mechanically reversed. The effect of the compounding by these differential windings on the main generator is to reduce the current in the main and the speed of the rolling motor, and so in a qualified way to imitate the action of a steam engine, which slows up when the torque is suddenly increased, the difference, however, being that by the electric method the slowing up can be controlled to suit the work in the rolls, and also prevent rushes of current tripping the circuit breakers.

This arrangement gives the effect of a differential compound winding on the main generator and a compound winding on the rolling motor respectively without the necessity of switching the main circuit, so that the working is as simple as the usual Ward-Leonard.

Hildegarde.—The Reversing Rolling Mill at the Hildegarde Works in Austrian Silesia is designed for reducing 2-ton ingots to billets, and for the first passes has to reverse about every six seconds. The rolls are driven by three continuous current motors, which are rigidly connected by couplings and supported in four bearings on a common bed-plate. Each motor has a normal rating of 1,200 h.p. at 330 volts; the maximum

speed is 120 r.p.m. The maximum horse-power of each motor for short periods is 3,600, so that 10,800 h.p. maximum can be applied on the roll shaft. The motors have Déri compensating windings and separately excited shunt windings.

Current is supplied by an equaliser set consisting of a 2,500 h.p., 3,000-volt induction motor, two 500-volt continuous current generators each of 1,500 k w. normal and 4,300 k.w. maximum output, and two fly-wheels running at from 300 to 375 r.p.m. The two cast-steel fly-wheels are 13 ft. in diameter, and each weighs 26 tons. The two continuous current generators and the three roll motors are permanently connected in series, and are controlled by Ward-Leonard regulation. Water-cooled brakes are provided on the fly-wheels, by which they may be stopped quickly in case of emergency. The fly-wheel effect is such that the power taken from the generating station is only about 25 per cent. of the maximum power required for the rolling mill.

Benrath.—A Continuous Rolling Mill equipment with a Kramer system of regulation, also by the A. E. G. Co , of Berlin, is working at Benrath, near Düsseldorf.

There are two motors connected on the roll shaft , one is an alternating current motor, 5,000 volts, 1,000 h.p. normal rating, 2,000 h p. maximum, at 80 to 100 r.p m. The other is a continuous current 300 h.p. motor.

The slip rings of the alternating current motor and the armature of the continuous current motor are connected to the two sides of a Kramer rotary converter (*vide* p. 208, *ante*) which stands alongside. The rotary converter is rated at 60 to 220 k.w. at from 120 to 360 r.p.m. By this combination the speed of the main motor can be varied 33 per cent. The shaft of the main motor is connected through a leather belt flexible coupling to the middle line of a three-high stand of rolls, a heavy fly-wheel being mounted on the shaft between the coupling and the roll gear box.

The supply is taken from the public mains, starting being effected with a liquid resistance. The maximum reading when the motor begins to move and before the oil film had been re-established in the bearings is 1,000 k.w. The main motor

is first started up and then the rotary converter is cut in with a simple switch arrangement, the continuous current motor being afterwards put in circuit and the speed regulated thereby.

The auxiliary machines for oil and water supply are all electrically driven. The tilting tables and live rolls are also electrically driven. Controllers for the motors of the tilting tables are arranged on an overhead bridge on either side of the rolls ; a separate stand is provided for the live-roll control, the man operating them being situated at the end of the main rolls. This means that three men are occupied in controlling the auxiliary motors in addition to the squad handling the steel.

The Plate Mill in the same works is equipped with a three-phase, 5,000-volt motor of 1,200 h.p. normal rating and 2,400 h.p. maximum at 150 r p m. This motor is connected by thirty-two ropes $1\frac{1}{2}$ in diameter to a 29-ft. fly-wheel weighing 85 tons and running at 30 r.p m., from the shaft of which the plate rolls are driven.

Voelklingen.—At these works near Saarbrucken there is a Continuous Rolling Mill for wire and iron rods driven by a 2,000-h p , 105 r.p.m. gas engine. Difficulty was experienced on account of the fluctuating load, and to assist the gas engine an electric motor was coupled on the same shaft. The size of the motor was chosen with a view of enabling it to undertake the whole work and so act as a spare to the gas engine, especially as it was the intention to remove the engine in the future.

The restricted space between the fly-wheel and the rolls did not permit the adoption of a normal construction. The outer bearing of the fly-wheel was removed, and a new shaft put into the fly-wheel with a solid half coupling, on to which the motor shaft is attached. This coupling runs inside the motor bed-plate, which has two bearings of unusually massive construction to support the weight of the fly-wheel. The energy is supplied at 5,000 volts three-phase, the rotor being wound two-phase in order to simplify the starting gear, which is of the liquid resistance type.

The engine is supplied with blast furnace gas and is allowed

to run continuously at full load, the regulation being done by the motor.

The mill consists of a three-stand roughing mill and a three-high finishing mill consisting of fourteen stands.

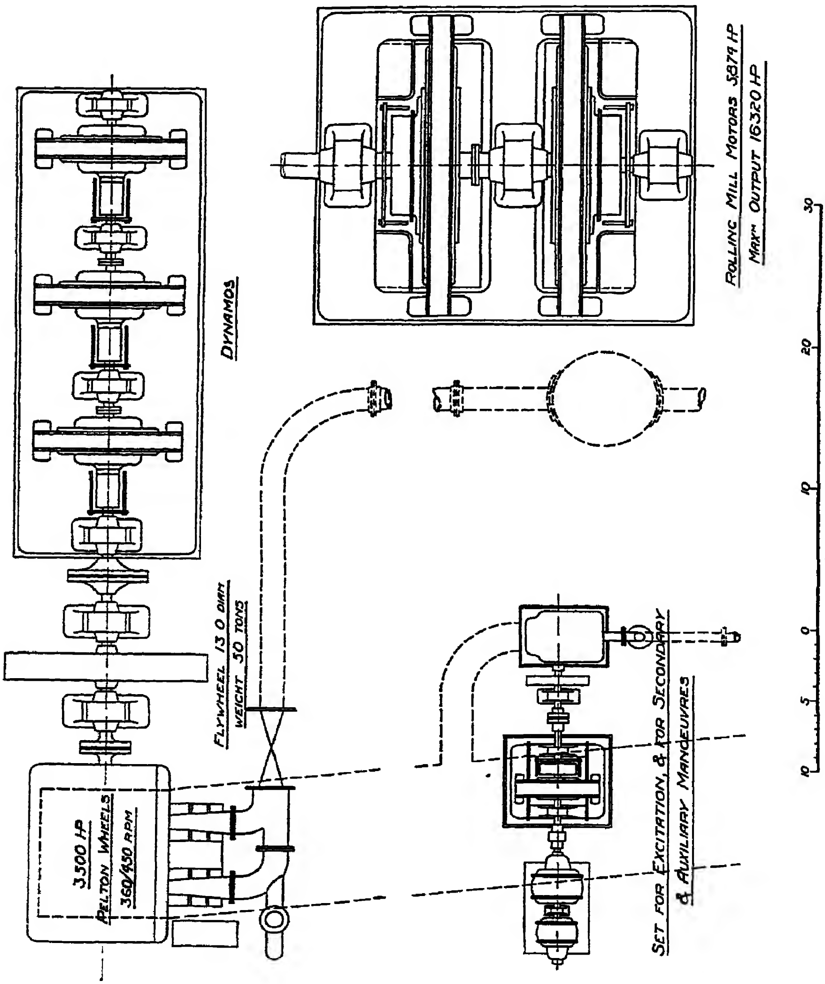


Fig. 84.—Terni reversing rolling mill

Both the gas engine and motor are connected direct to the roughing mill. A rope pulley, 23 ft. in diameter, weighing 100 tons, which also acts as a fly-wheel, drives the first set of finishing rolls by means of nine ropes 2 in. in diameter at a speed of 250 r.p.m. The second and third sets are driven by twelve

and fifteen ropes respectively, and run at speeds of 400 and 500 r.p m. respectively.

The ingots are 4 in. by 4 in. section, weighing 300 lbs. each, and are rolled into a rod of 0·2 in. to 1·2 in. diameter, and strip iron 0·7 in. to 1·2 in. in width.

Measurements show that with the motor alone driving it developed 2,000 h.p. normally, and was capable of giving 100 per cent. overload. By means of the coupling the gas engine can be disconnected, when the motor undertakes the whole work alone. The chief interest in this plant lies in the parallel running of the gas engine and the three-phase induction motor.

Terni Steel Works.—This installation in Italy is specially interesting from the point of view that the energy for driving the Reversing Rolling Mills is generated from water-power.

The power is at present obtained from falls yielding about 66,000 gallons per minute at 610 ft. head, which corresponds to 12,000 h.p. at the turbines.

One of the most interesting features of this plant is the armour-plate mill, the necessary power for which is furnished by a 3,500 h p. turbine with two Pelton wheels, 3 ft. $3\frac{1}{8}$ in. in diameter, the turbine runs at a speed of 360 to 450 r p.m and develops with almost a uniform efficiency from 1,500 to 3,500 h.p. on a water consumption of 176 to 440 gallons per second at the respective speeds.

The turbine is coupled direct by means of an elastic coupling to a fly-wheel 13 ft. in diameter, weighing 50 tons, and three Lahmeyer continuous current generators for supplying the mill motors. The general arrangement is shown in Fig. K4.

The motor of the mill is reversible and built in two parts, It is coupled to the mill by means of an elastic coupling of special construction and controlled on the Ward-Leonard system. It develops 5,874 h.p. at 90 r.p.m. and 600 volts, and can take short overloads up to 16,320 h.p., of which the turbines supply one-fifth and the fly-wheels four-fifths.

The Gary, U.S.A., Continuous Rail Mill is the largest in the world, and presents several interesting features. The main

rolls of the mill are driven by six induction motors having a combined capacity of 22,000 h.p., made up of the following units :—

Two 2,000 h.p.	..	at 214	r.p.m.
One ,,	..	,, 68	,,
One 6,000 h.p.	..	,, 88	,,
One ,,	..	,, 83	,,
One ,,	..	,, 75	,,

The capacity of the mill is 4,000 tons of finished rails per twenty-four hours. It is not only the largest, but also claims to be the only electrically driven mill in the world, rolling rails direct from the ingot without reheating.

Another interesting feature of the plant is the battery used for equalising the load working in connection with a split-pole converter (*vide*, p. 257, *ante*).

The effect of the battery regulation on the operation of the plant is said to be very marked. It has led to the shutting down of one of the 2,000 k.w. gas engine units, and the voltage regulation since the battery came into use is excellent.

There are two series of chloride batteries, each of 125 cells for 4,220 amps. at the one-hour rate, or 8,640 amps. at the normal discharge rate. They work in parallel, and are capable of giving 17,280 amps. at 200 to 230 volts, but discharges as high as 25,000 amps. (= 5,000 k.w.) have been taken. The two split-pole converters are wound for six phases. Each has a rating of 6,800 amps. continuous current at a voltage of 225 to 275; the momentary overload is 10,000 amps. at 300 volts when working as a true converter, or 14,000 amps. at 200 volts continuous current input as an inverted converter. The power-house contains seventeen 2,000 k.w. alternating current units, of which fifteen are gas driven and two steam driven, and two 2,000 k.w. continuous current gas-driven units.

CHAPTER XI

MACHINE TOOLS AND CRANES

THE application of electric motors to machine tools is too general and well accepted to need special comment at this time, and the space at our disposal will not permit a lengthy description of the application of electricity to small tools. Heavy industries, however, always have light work and light tools to be operated in connection with them, so the author may be permitted to say a word or two about electrical driving in general. Here, as elsewhere, the main idea in applying electricity is to save stand-by losses and losses in transmission.

If light machine tools of one class can be arranged in groups, it will generally be found convenient and economical to adopt group driving and not individual driving. If, however, the tools are not of the same class and have to be run separately and at odd times, individual driving may be the better plan to adopt. Many shops have been equipped with individual driving, carried to such an extent that it would appear to have been a fetish rather than economical considerations that decided the lay-out.

For driving machine tools, cranes, and nearly all purposes in works variable speeds are essential; consequently continuous current is preferable to alternating. The advent of the compensated field motor and the interpole motor, whereby speed control is obtained without sparking troubles, has given a great impetus to individual tool driving. Before the development of the interpole motor the multiple voltage-control system attained some prominence. In this system three generators or balancers of different voltages were connected in series, and speed control was obtained by connecting the motor across one or more of them. Where the supply is alternating it is sometimes necessary to convert it to continuous current by motor generators, which it is advisable to equip with a fly-

wheel in order to equalise the load. Speed control is generally effected by regulating the fields of the motor, but series-parallel control may advantageously be adopted in many cases. In large systems 3,000 or 5,000 volt three-phase may be used for distribution and for large motors, and for conversion to continuous current for small motors, or where variable speeds are called for. On continuous current schemes the pressure may conveniently be taken as 400 to 500 volts for large motors and 200 volts for small ones.

The motors should be standardised and chosen with a view to facilitate exchange and repair in case of breakdown, should be insulated with non-hygroscopic material, preferably impregnated, and may often with advantage be all selected of the "water-proof" class. Where the machines are standing practically, if not actually, in the open air, these qualities are essential, and even when they are situated under cover the "water-proof" protection is valuable. The entry of metallic chips and dust must be guarded against by efficient screening.

Switch-gear should be of a particularly robust type, and the starting switches should be provided with a no-load release in addition to the usual over-load cut-outs. It is good practice to put an ammeter on motors working heavy tools, especially in these days of "speeding up."

In the United Kingdom the Electricity Rules made by the Home Office under the Factory and Workshops Acts must be borne in mind ; in this connection the Memorandum (Form 928, Feb., 1910) by H.M. Electrical Inspector of Factories will be found useful.

Complete supervision of the electrical equipment is essential ; neglect of this point may prove costly. Where such supervision exists failures and breakdowns are remote. A short time since the author visited a large steel works where electricity has been extensively employed for the last twelve years or more. There are now upwards of 400 motors and 500 arc lamps in use, all of which are kept in repair by the "hospital" staff on the works. In the hospital there were only four armatures, two of which were under repair and two waiting to be repaired at the time of his visit.

Heavy Machine Tools.—Fig. 11 shows a very fine twin-jib armour-plate drilling and tapping machine of the heaviest type by Messrs Joshua Buckton & Co. This is an excellent example

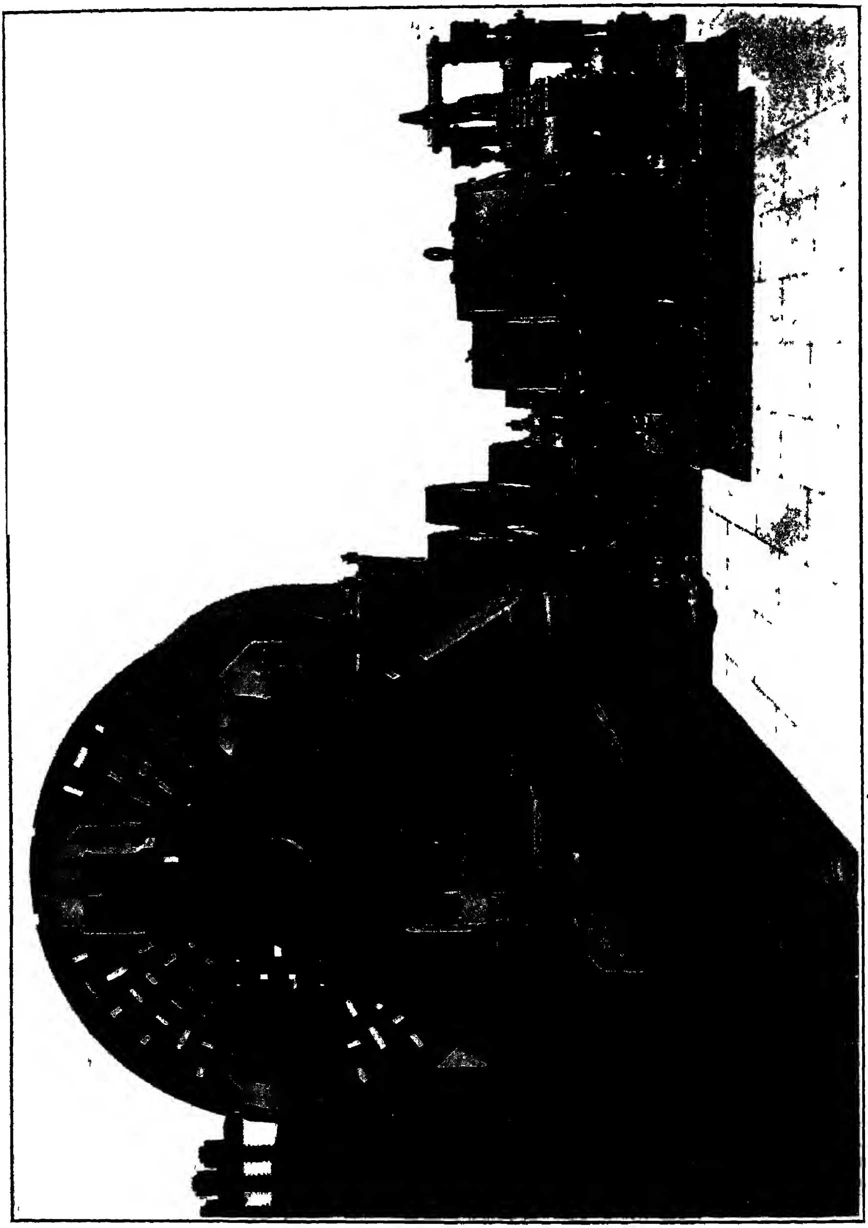


FIG. 12.—Buckton's lathe for 13·5″ guns Headstock end

of a special tool made for a particular purpose. Each of the two jibs can be independently traversed to and fro upon the bed by a 10 h p. continuous current motor, which is situated at the base of its column. Each of the spindles is driven by a continuous current 25 h.p motor on the top of its

FIG. L3 —Buckton's lathe for 13 5″ guns.

column. As these machines have not only to drill but to tap holes up to 5 in. diameter in armour-plate, the spindle must be under very complete control for stopping, starting, and reversing, all of which is effected by means of the motor control gear.

The motor is of the variable-speed type for a range of 3 to 1

and provided with a reversing controller and a solenoid brake, which enables the spindle to be controlled with the degree of

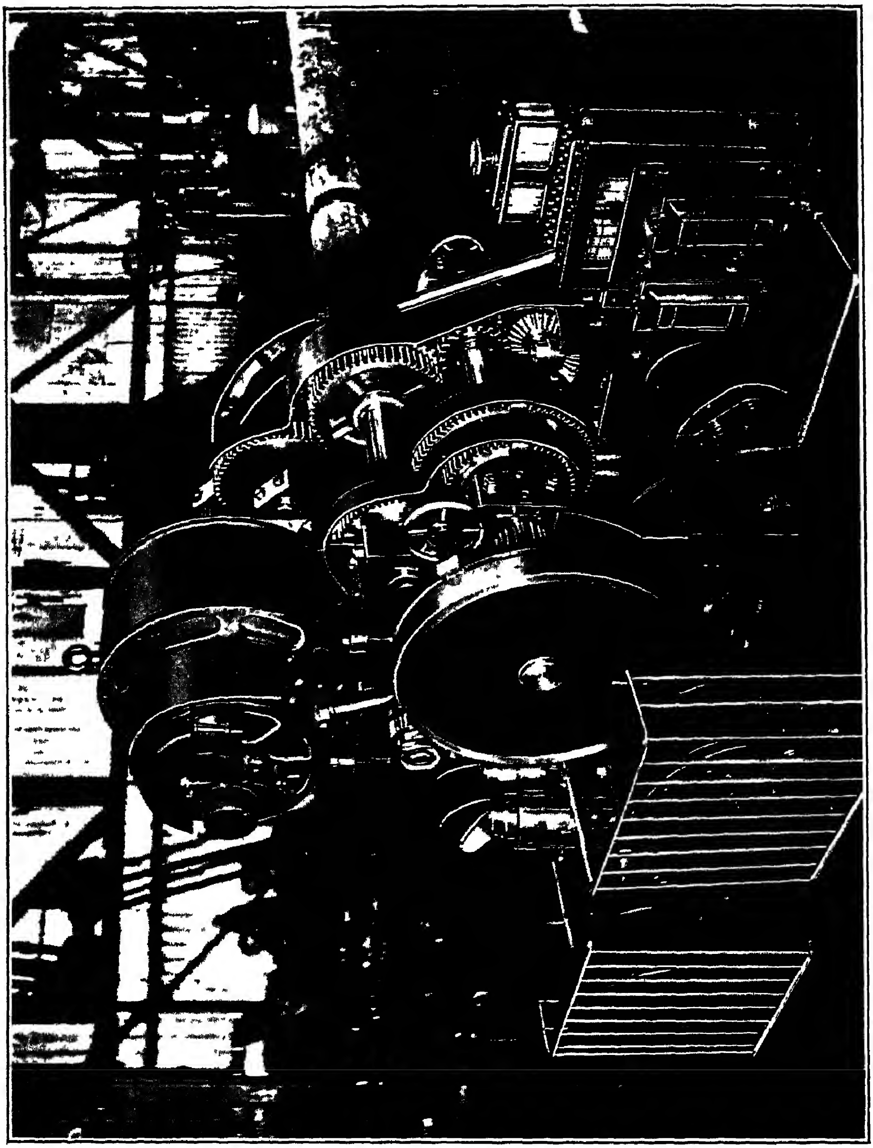


Fig 154 —Lathe with rain-proof motor

nicety necessary to tap a blind hole. The spindles can be swivelled to any angle, and are always uniformly balanced.

A horizontal hot bloom shears for cutting hot steel blooms 8 in. square is driven by a direct-coupled continuous current electric motor of 80 h.p. which is connected through gearing, to the eccentric shaft actuating the reciprocating shear slide.

Figs. L2 and L3 show the head-stock end and a general view of a large gun lathe, by Messrs. J. Buckton & Co., for dealing with 13·5 in. guns. The lathe is driven by a continuous current direct-coupled motor of 100 h.p., having a variable speed range of 6 to 1, which drives two twin-worm wheels upon the lathe spindle through a train of spur gear, the work being equally divided between the two wheels, and the thrust of the worms being taken upon compensating oil pivots. An auxiliary motor of 5 h.p. is used for moving the tail-stock. This is one of the largest gun lathes in existence, and handles the heaviest gun used in the navy, which when complete weighs about 78 tons.

Fig. L4 shows a variable speed rain-proof type 40 h.p. continuous current motor by Messrs. Laurence, Scott & Co., running from 300 to 750 r.p.m., driving a large Shanks lathe at Messrs. Harland and Wolff's Ship Repairing Yard at Southampton. The controller is seen fixed on the floor near the head of the lathe.

All the machines in this yard are of the rain-proof type. When deciding on the equipment of this new yard rain-proof type motors were generally adopted—in some cases because the machines were placed actually in the open, or in more or less temporary sheds; but in many instances the type was adopted to prevent metal chips and turnings from getting into the motor. This latter point might have been met by the adoption of ventilated motors protected with gauze grids, but the rain-proof type was used in preference to secure the maximum amount of interchangeability and security.

In the same yard a 20 h.p. compound wound motor drives a Cameron punch, which will make 2-in. holes in a 2-in. boiler plate. The motor is mounted on a spring suspension and provided with a tramway type controller.

Planing Machines.—Belt-driven Planing Machines were all formerly reversed by cross-belts, and generally arranged for

Fig L5 — Buckton's tandem table planing machine

the bed to travel at a higher speed on the return stroke. The first planing machines driven electrically were reversed in the same way. Several methods of reversing planing machines are now in vogue.

Fig. L5 shows a variable speed heavy type planing machine by Messrs. J. Buckton & Co., with tandem tables, each of which will plane 61 ft. long by 5 ft. wide by 5 ft. high at a cutting speed of from 17 ft. to 60 ft. per minute and a return speed of 136 ft. per minute. The machine is driven by a 50 h.p. reversing motor coupled direct to the machine. The motor is driven by current from one of the Lancashire Dynamo Co.'s motor generator sets, which is placed upon the top of the machine and runs at constant speed. The motor of the motor generator can be arranged to be driven either from alternating or continuous current. The generator voltage can be varied, thus giving the changes of speed on the machine over a total range of 8 to 1. The machine takes the same strength of cut at all speeds, the horse-power given out by the planer motor being directly proportional to the cutting speed.

Messrs. Buckton also make a speciality of a double-cutting planing machine which is driven by a reversible motor at the same speed in each direction. Fig. L6 shows such a machine, which is driven by a 30 h p. motor running at 600 r p.m , and puts a 15-ton pull on the table through a slow-running heavy belt. The belts do not shift on fast and loose pulleys. but are themselves tightened and loosened alternately, and when at half-stroke of the jockey pulley each runs loosely in a loop under its respective pulley without touching it. The cutting speeds are 17, 35, and 60 ft. per minute, the return speed 136 ft. per minute. The belts are carefully sewn and are endless, without any laced or metallic joints, any stretch in a new belt due to working is taken up by moving the position of the jockey pulley. The belts are 8 in. wide, and as they are not subject to contrary flexure round the jockey pulleys and encounter no edge friction from belt-striking forks, they are free from the elements of self-destruction usually found in heavy planing machine belts or belts used with a jockey pulley.

The broad belts and low velocity instead of narrow belts and high velocity are chosen to keep down the inertia, which is the

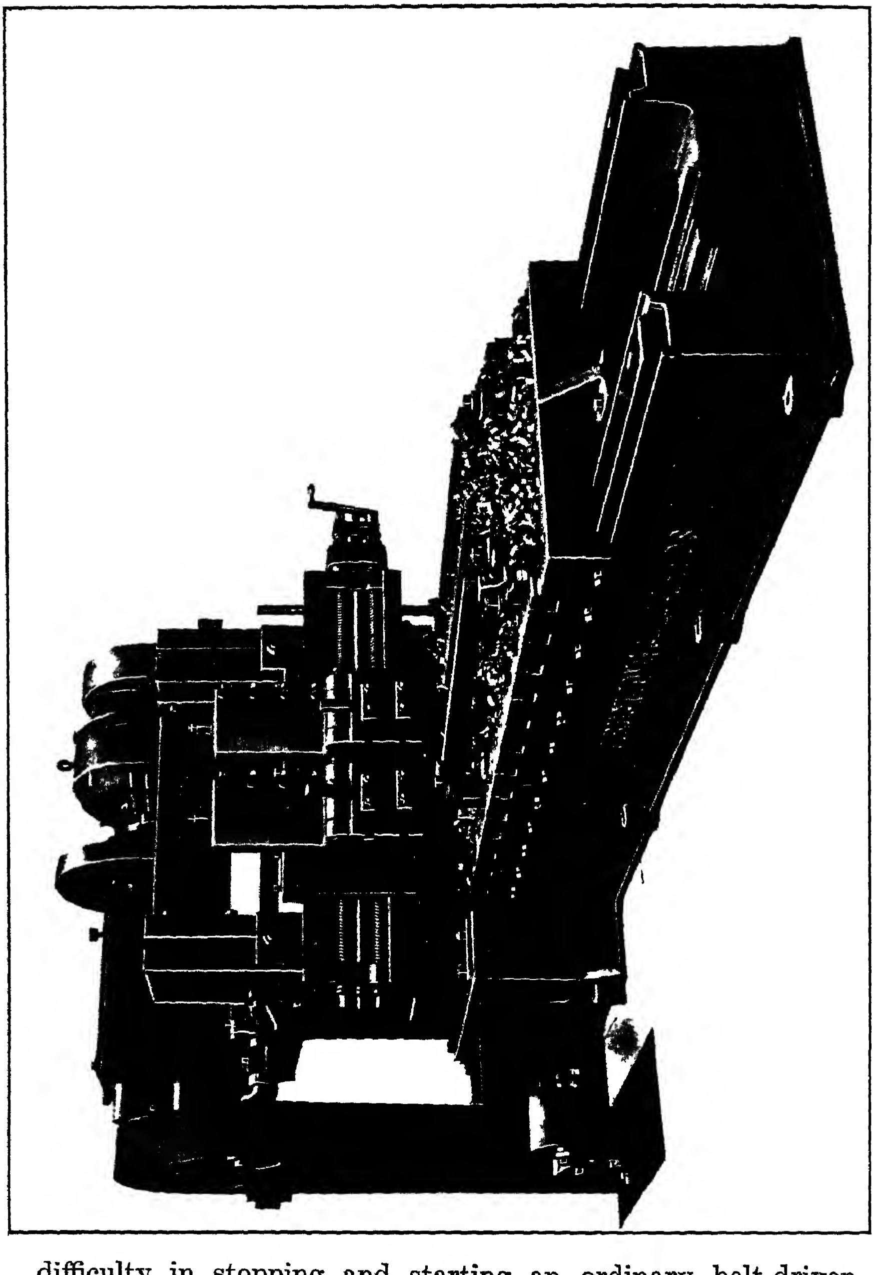


Fig 146 —Planing machine

difficulty in stopping and starting an ordinary belt-driven planer. The photographs from which these figures have been prepared were kindly supplied by Mr. J. Hartley Wicksteed,

Past President of the Institution of Mechanical Engineers, who fully described Messrs Buckton's system of double-cutting and high-speed planing machines in a paper read in November, 1911, before the Institution of Mechanical Engineers This application of jockey pulleys, which has given the greatest satisfaction in operation, is very interesting, particularly when the experience with jockey pulleys elsewhere is remembered. In the ordinary jockey pulley arrangement the belt is bent both ways, as the pulley usually runs on the outside of the belt. To overcome this difficulty link belts have frequently been employed, but they are very heavy, and for a given width of pulley there is only half the useful surface for grip which obtains with a plain belt. In Messrs. Buckton's device this feature is eliminated.

The author was surprised on a recent visit to the Continent to see some 400 h p motors driving air compressors with a jockey pulley and hearing from the engineer that they were giving absolute satisfaction The system used in that case is the "Lenix," in which the jockey pulley is pivoted generally concentrically, with the driving pulley, so that as the belt comes round the tendency of the jockey pulley is to wrap the belt round the driving pulley

The Ward-Leonard control has been introduced by the Lancashire Dynamo Co. with great success in the driving of Buckton planers. The equipment consists of the usual "starting generator," which supplies the energy to drive the direct-coupled planer motor Reversing and speed regulation is effected by field control of the generator, hence belts and gearing are done away with.

The main advantages of this system are :—

(1) Large range of speeds ;
(2) Gain of time at reversals, hence increased output of planer ;
(3) Regeneration of current, as the momentum of the moving parts is absorbed by the motors and in part returned to the line, thus providing an efficient brake which reverses the motor instantaneously ;
(4) Steadiness of working.

Mr. A. D. Williamson, of Messrs. Vickers', Ltd., described

the Vickers' system of speed control of planing machines before the Institute of Electrical Engineers, Vol. XXXII., p. 925.

This system consists of a variable speed motor with suitable starting and reversing switches and a speed regulating switch with resistance adjustable by hand.

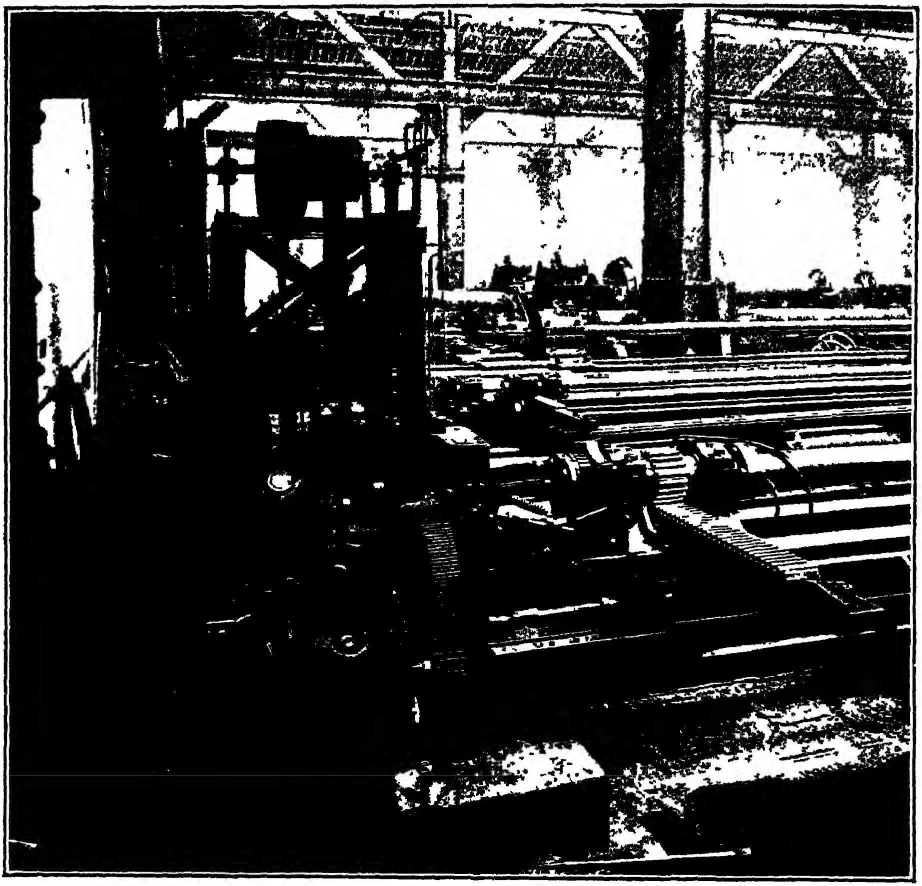


FIG L7.—Vickers' gun-rifling machines.

The planer is driven by the motor through suitable gearing. On the cutting stroke the motor runs at any convenient speed for the work in hand; at the end of the stroke the motor reverses automatically, and a resistance is inserted in the field circuit which raises the speed for the quick return stroke. At

the end of the return stroke, and just before the reversal, the field resistance is short-circuited, which slows down the motor and provides a strong field in which to reverse the armature.

The reversing is controlled by tappets, which can be fixed at any point on the table to give the length of the stroke necessary for the work in hand. The sparking is all taken care of by carbon blocks on the switches, and the wear and tear is so small that nothing in the way of repairs further than a few blocks were required to keep an armour-plate planer driven by a 20 h.p. motor running night and day for six years.

Such systems of electric control prevent the loss of time due to the slipping of belts, the waste of energy in driving the belts and reversing pulleys, and the expense of belt renewals, which is a considerable item on large planers.

In a horizontal planer 12 ft. by 5 ft. by 5 ft., by Messrs. Fairburn McPherson, fitted with the Vickers' reversing drive, the motor is of 20 b.h.p., with a speed range of 300 to 900 r.p.m. giving cutting speeds of 25 ft. to 75 ft per minute, and a return speed of the table of 75 ft. per minute. One of these planers was exhibited at the Olympia Exhibition in 1905.

Sundry Tools.—Fig L7 is interesting, as it shows a Gun Rifling Machine in the foreground fitted with Vickers' patent system of beltless reversing drive, while the machine in the background is worked by open and cross belts in the old method. The gain in space and convenience is very marked.

A Plate Edge Planer by Messrs. Hugh Smith & Co. is driven by a 20 b.h.p. motor fitted with Messrs. Vickers' reversing drive. The machine is used to plane steel plates 26 ft. long by $1\frac{1}{2}$ in. thick at 40 ft. per minute, and removed a $1\frac{1}{4}$ in. cut, by $\frac{1}{13}$th of an inch feed, at 40 ft. per minute from mild steel plates on an actual test.

A Railway Wheel and Tyre Lathe by Messrs. G. A. Harvey, Ltd., is driven by a 40 b.h.p. Vickers variable speed motor with a speed range of $2\frac{1}{2}$ to 1. The lathe was designed to take the heaviest cuts with high-speed steel tools. The changes in the spindle speed of the wheel lathe are obtained entirely from the motor. In the tyre lathe there is, in addition, a change of gear by which a total variation of speed is obtained of 16 to 1.

A Boring and Turning Lathe, 4 ft. 6 in. centres, is driven by a 40 b.h p. variable speed Vickers' motor running from 400 to 800 r p m., and giving face-plate speeds of ½ to 36 r.p.m. with 100 intermediate speeds. The machine is also fitted with a 10 b.h.p motor running at 600 r.p.m. and a quick feed for loose head-stocks and slides.

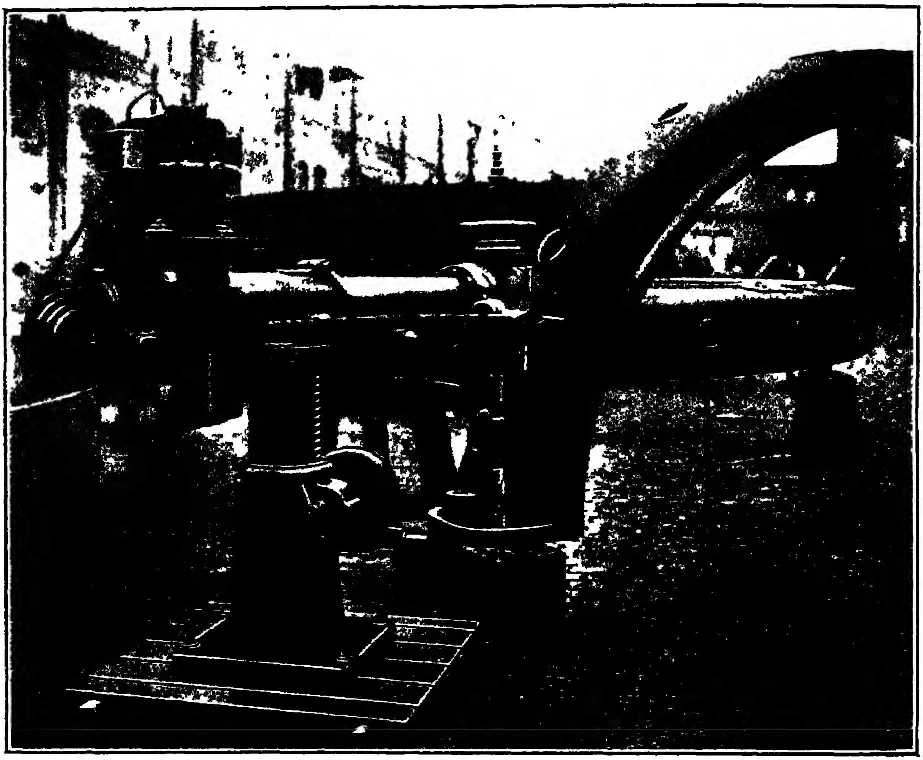


Fig LS —Portable drill

Where heavy parts have to be tooled and the amount of tooling is relatively small it is frequently convenient to take the tool to the work instead of the work to the tool. Fig. LS shows a portable drill working in an open yard on heavy castings intended to form the stator of slow-speed alternating generators. The economy in tooling in this way is obvious.

The above give a general idea of the size of motors required,

and the class of work that they may be called upon to do, in the electric driving of machine tools.

Cranes and Travellers.—In no class of heavy tool is the advantage of electric driving more marked than in Cranes and Travellers. In the special cranes, such as are used for building work and are commonly called "Scotchmen," the convenience

FIG. L9 —Travelling crane with gantry built into roof.

and economy of the electric motor as compared with the steam engine and boiler is evident by the continued increase of such machines. The bigger the crane the bigger the advantage of electric driving. The engine and boiler is certainly of some advantage as counter-weight, but counter-weight may be more cheaply and economically provided than in the shape of an engine and boiler.

In the case of travellers for shop work fly-ropes were the only alternative to an engine and boiler on the traveller, and these present considerable difficulties in arrangement as well as wear and tear and other objectionable points.

For light work walking cranes of the post type are frequently used. The foot of the post of such a crane is stepped into a long carriage, which runs on a single rail ; the length of the carriage serves to keep the post upright in one direction ; the head of the post is guided in the roof between two rails, which serve as a guide and keep the post upright in the other direction. Such an arrangement is inconvenient on account of the floor space occupied. Fig. L9 shows an alternative arrangement adopted in the Frankfort Works of the Lahmeyer Co. ; the gantry for the crane was specially designed as part of the roof for the new shops, and the arrangement proved extremely convenient.

An example of an electric crane by Messrs. Stothert and Pitt at Heysham Docks lifts 3 tons at a fixed radius of 34 ft., and is erected with the front wheels on the quay wall. This crane is what is known as the half-portal type, with a span of 31 ft. 2 in. and a difference in rail level of 20 ft. 4 in. between the quay wall and the building upon which the back wheels of the crane run. The lifting and the slewing motions are operated by separate motors of 40 b.h.p. and 7 b h.p. respectively. In a crane of this description travelling motion is seldom required, and so is provided for by hand-power only.

A 50-ton electric crane at Southampton Docks by the same makers lifts 50 tons at 87 ft. radius and runs on rails of 25 ft. 6 in. gauge. The lifting motion is operated by two 50 h.p. motors, with series-parallel control, at a speed of 16 ft. per minute for full load, or 56 ft. per minute for light loads. The derricking speed is 8 ft. 6 in. per minute, and is operated by an 80 h p. motor. Slewing is effected by a 25 h.p. motor at the rate of one revolution in two-and-a-half minutes. The crane travels on twenty wheels at the rate of 30 ft. per minute when fully loaded : this motion is operated by a 50 h.p. motor.

Fig. L10 shows a 150-ton Giant Crane, at Messrs. John Brown & Co.'s Works, Clydebank, the steelwork of which was made by Sir William Arrol & Co., while the hoisting gear was made by Messrs. Stothert and Pitt, Ltd. The height to

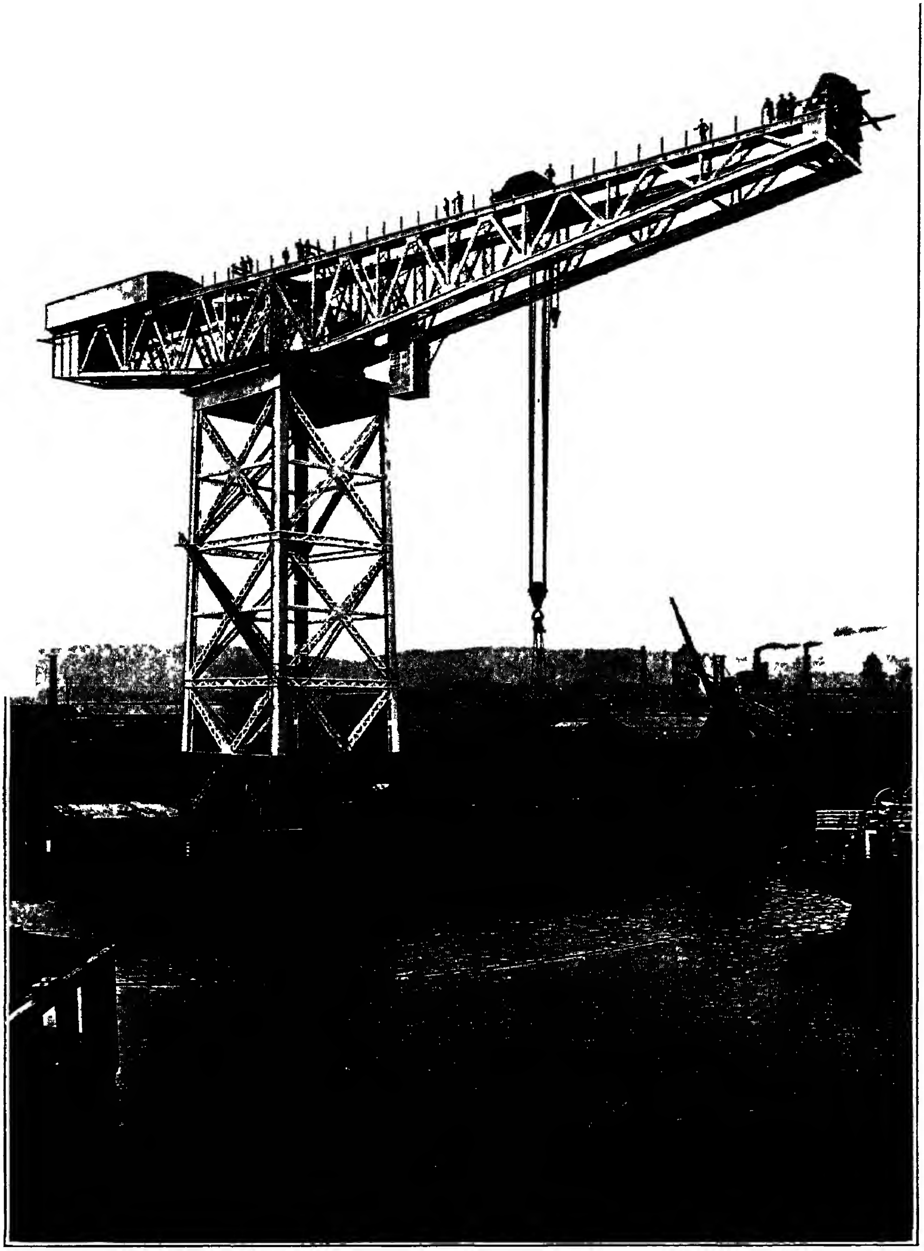


Fig. L10.—150-ton Giant crane.

the top of the tower from the ground line is about 125 ft. and to the top of the rails on the cantilever 153 ft. 4 in. This crane will lift—

150	tons at	85 ft.	radius at	5 ft. per minute, or
120	,,	100 ft.	,,	,, ,,
100	,,	114 ft.	,,	7 ft. 6 in. per minute, or
80	,,	133 ft.	,	,, ,,

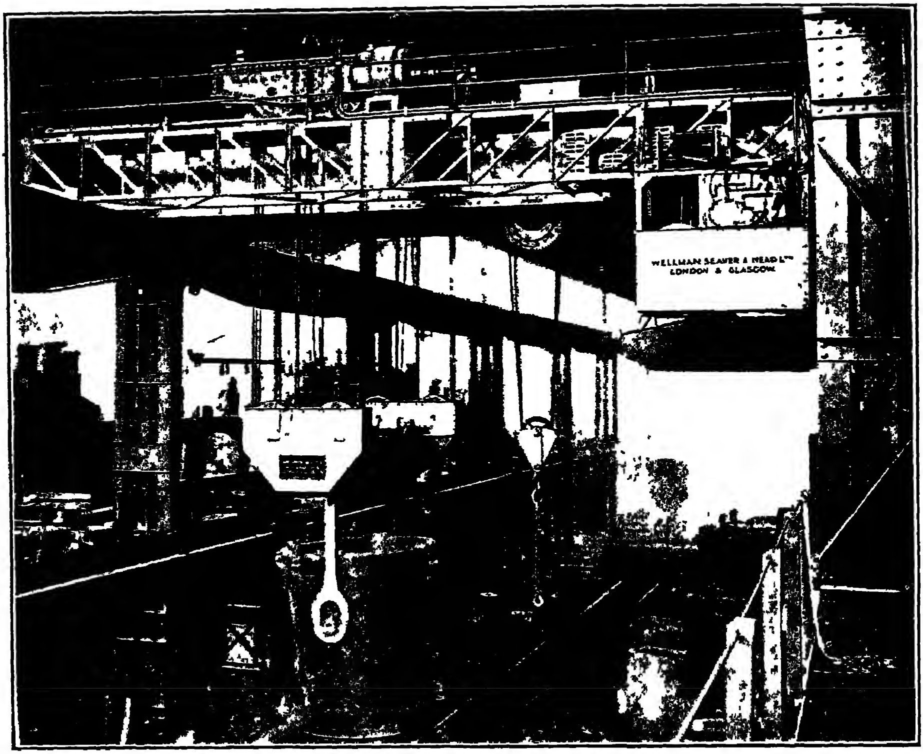


FIG L11.—150-ton ladle crane.

The main hoist is driven by two 50 h.p. motors with series-parallel control.

There is also an auxiliary hoist which is driven by a 50 h.p. motor, provided for loads up to 30 tons, which will handle

30	tons at	12 ft. 6 in.	lift per minute, or
$7\frac{1}{2}$	,,	50 ft.	,, ,,

The racking motor is 50 h.p., and will give speeds for

150 tons at	40 ft. per minute, or	
30 ,,	100 ft. ,,	

The slewing motor is also 50 h.p. and the slewing speed for 150 tons is one revolution in ten minutes, and for 30 tons one revolution in five minutes.

In a 40-ton Traveller constructed for a Sheffield Steel Works, the span of which is 81 ft. 9 in., four motors are provided, as under.

Main hoist, 40 h.p.	..	speed 10 ft. per minute.
Auxiliary hoist, 30 h.p.	..	speed 20 ft. for 15 tons, or 40 ft. for 5 tons.
Cross traversing 13 h.p.	..	speed 100 ft. per minute.
Traveller motor, 45 h.p.	..	speed 200 ft. ,,

The gear throughout is of cast steel with machine-cut teeth.

Fig. L11 shows a 150-ton Ladle Crane by Messrs. Wellman-Seaver and Head with a 25-ton auxiliary trolley. The crane is operated by the following motors :—

Main hoist, 80 h.p. motor ;
Cross traverse, 35 h.p. motor ;
Long travel, 60 h.p. motor ;
Auxiliary hoist, 60 h.p. motor ,
Auxiliary cross traverse, 10 h.p. motor.

The gear for carrying the ladle is clearly shown. The ladle is tipped by the aid of the auxiliary hoist. The crab for the main hoist runs on the top of the girders, while the auxiliary hoist runs inside the girders ; the swinging girder which carries the ladle is of such a width that the auxiliary hoist can pass through the ropes.

Speeds.—In connection with electric travellers, the purpose for which the machine is intended has to be considered when settling the speeds. A traveller which is used as a transporter can run faster and does not require such nicety of control as a traveller which is used, say, in a foundry where core boxes have to be lifted, or in a workshop where plant has to be

assembled or dismantled. Table L1 is interesting as showing some speeds used in actual practice.

These speeds may be modified by considerations of the height and lift and the length of travel required. It is also important to consider whether the crane attendant operates the crane by ropes from the floor or is situated in a cab carried by the crane, which is the better and more usual practice.

TABLE L1.

SPEEDS OF CRANES.

—		Load in Tons	Feet per Minute.			
			Lifting	Slewing	Derricking, Racking, or Traversing	Travelling
Dockside Crane,	40 ft. radius	3 1½	120 240	400	—	Hand
,, ,,	46 ft. ,,	3	120	220	45	,,
,, ,,	45 ft. ,,	4	120	300	33	50
,, ,,	46 ft. ,,	10 5	45 90	100	20	Hand
Coaling ,,	36 ft. ,,	21	25	250	—	—
Forge ,,	24 ft. ,,	15	10	75	15	—
Railway, Goliath,	56 ft. span	10 5	10 15	—	80	150
Power Stn. Crane,	62 ft. ,,	25 light	12 33	—	80	130
Ladle Crane,	90 ft. ,,	50 10	15 30	—	—	250
Boiler Shop, Goliath,	80 ft. ,,	60 10	6 36	—	80	150
Herbert Morris' Standard Power Station Crane	20 ft. to 80 ft. span	5 2	15 38	—	75	250
,,		10 3½	10 30	—	75	250
,,		25 6	7½ 30	—	65	200
,,		50 12½	6 24	—	65	200
,,		75 18½	5 20	—	60	160

The speed of lowering may, in certain cases, be even more important than the speed of lifting. For instance, there is a 100-ton crane at the Woolwich Arsenal which is used for lower-

ing gun tubes into the oil-tempering baths. The clear headway under the crane is 98 ft., and this crane frequently has to lower pieces weighing 75 tons 75 ft. in thirteen seconds—in

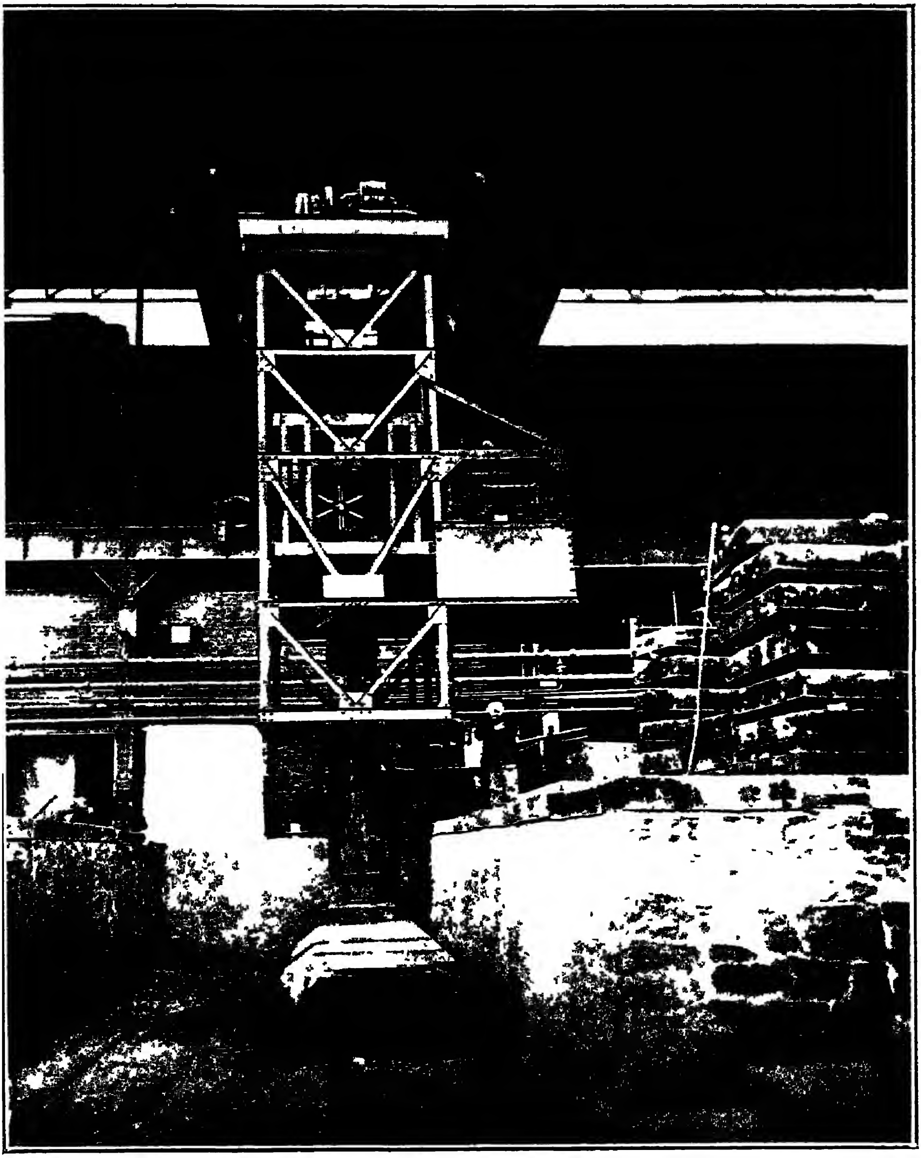


FIG. L12.—Wellman-Seaver and Head's stripper.

fact, pieces weighing 75 tons have been lowered 75 ft. in ten seconds, but this is as much due to expert handling as to crane construction.

Steel Works.—In no industry has the benefit of electric driving been more appreciated than in Steel Works. The use of electricity for driving the rolls and doing the heaviest work has already been considered, but it is even more valuable as a labour-saving agent in its ready application to the various ancillary operations in the steel mill.

The elevator equipments which form part of an up-to-date blast furnace plant are best operated electrically, as then the automatic and safety devices which make for economical and regular working can be most easily applied.

A visit to an up-to-date steel works is most impressive in its exhibition of machines which show the highest combination of skilled mechanical and electrical design ; so happy, indeed, is this application of electricity that the motors are quite unobtrusive parts of machines, which appear instinct with life and almost as having discriminating powers. Such machines originated in America and Germany, but are now made to such perfection in England that they are in some cases bought by German steel makers, who prefer them to their local productions.

Strippers.—Steel ingots are cast in long taper moulds, open at each end, which stand on their bases ; the operation of stripping the mould is effected by a machine which, as it were, grips the head of the mould with a finger and thumb and while lifting it presses the ingot down with another finger to prevent its being lifted too. This is done by a machine the main outline of which resembles a travelling crane. The crab carriage contains the stripping device, which in German types is operated by screws and gearing, but in the English type by wire ropes.

Fig. L12 shows the Wellman-Seaver and Head model, which first strips the mould from the ingot, then charges the ingot into the soaking pits, and also draws the re-heated ingot from the pit and places it on the mill chair at the end of the live rolls, which pass it to the rolling mills.

The old type of vertical rotating telescopic gripping device is superseded by an arrangement of dogs suspended by wire ropes inside a vertical frame, which serves to guide them and to hold the controlling gear. This frame forms the crab carriage of a traveller. The dogs can be turned round their

FIG. L13 —Open-hearth rolling furnace

vertical axis as well as raised or lowered, and at will the centre ram can be raised or lowered independently of the dogs. By the Wellman system a stripping pressure of 250 tons can be applied without transmission through a screw.

An **Open-Hearth Rolling Furnace** by the same makers, which takes a 20-ton charge, is shown in Fig. L13. The furnace

is rolled or tipped by a 24 h.p. electric motor working a rack and pinion through a worm-gear for the first reduction and double-helical gear for the second reduction.

Open-Hearth Charging Machines are made in at least eleven different and distinct types by Messrs. Wellman-Seaver and Head. Fig. L14 shows the largest of its type which has been

FIG. L14.—Wellman-Seaver and Head's charging machine.

built, and which is working at the Eston Works of Messrs. Bolckow, Vaughan & Co., Ltd., handling an 8-ton ingot. Such a machine can charge a 50-ton furnace in twenty minutes. The charging bar can be raised, lowered, tilted or turned on its axis ; it is provided with a tee head and locking pin, so that it can either pick up a box of scrap or broken pig, or the peel which carries an ingot, or a piece of scrap too large to be put into a box. There are four motors with this machine, three

of them 30 h p. each for the hoist, the cross-traverse, and the long travel respectively, while the bar is turned by a motor of $5\frac{1}{2}$ h p.

Fig. L15 shows a 12-ton overhead Slab Charging Machine, which is designed for handling slabs ranging from 3 to 12 tons in weight. It is provided with a 30-h.p. motor for hoisting, a 25-h.p. motor for slewing, a 55-h p. motor for the long travel,

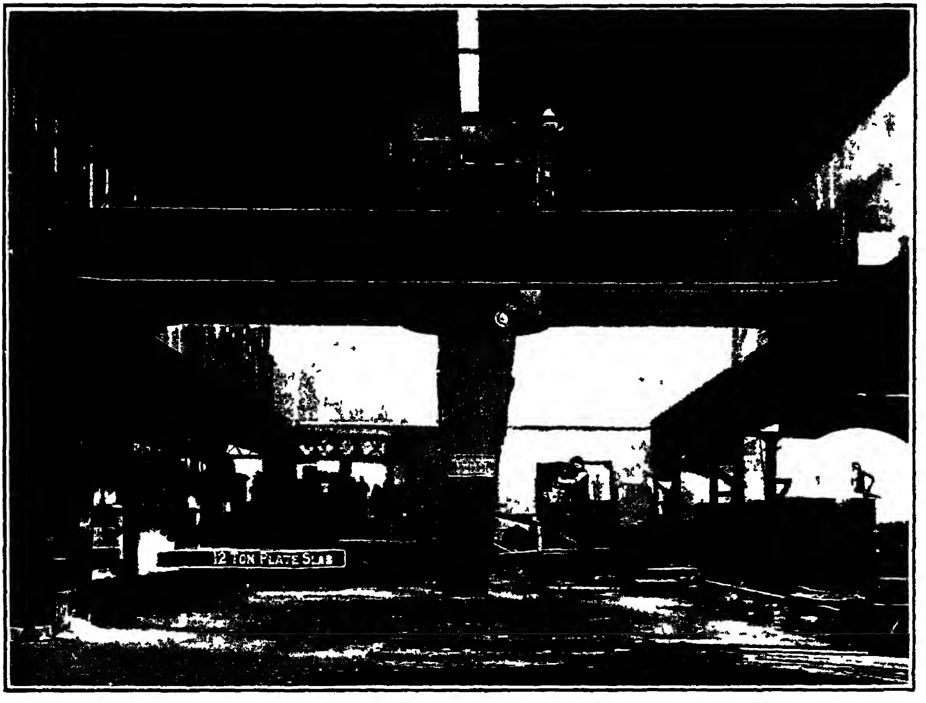


FIG L15 —Wellman-Seaver and Head's charging machine. Overhead type

a 30-h.p. motor for the cross-traverse, while the alligator jaws are operated by a 25-h.p. motor. The range of lift of the hoisting motor is about 7 ft , which brings the arm holding the slab up to about the position of the name-plate on the photograph. This hoisting is necessary to adjust the level of the slab for putting it into the furnace, but is utilised most for stocking purposes. The alligator grab is Wellman's patent; its gripping power is in proportion to the weight of the slab lifted.

A 4-ton Open-Hearth Charging Machine by the same makers is operated by five motors: the hoist 25 h.p., cross-traverse 25 h.p., long travel 35 h.p., slewing 7 h.p., and the bar turning is effected by a 7-h.p. motor.

Such machines not only save labour, but time, and so prevent loss of heat, as the furnace doors are open for the minimum

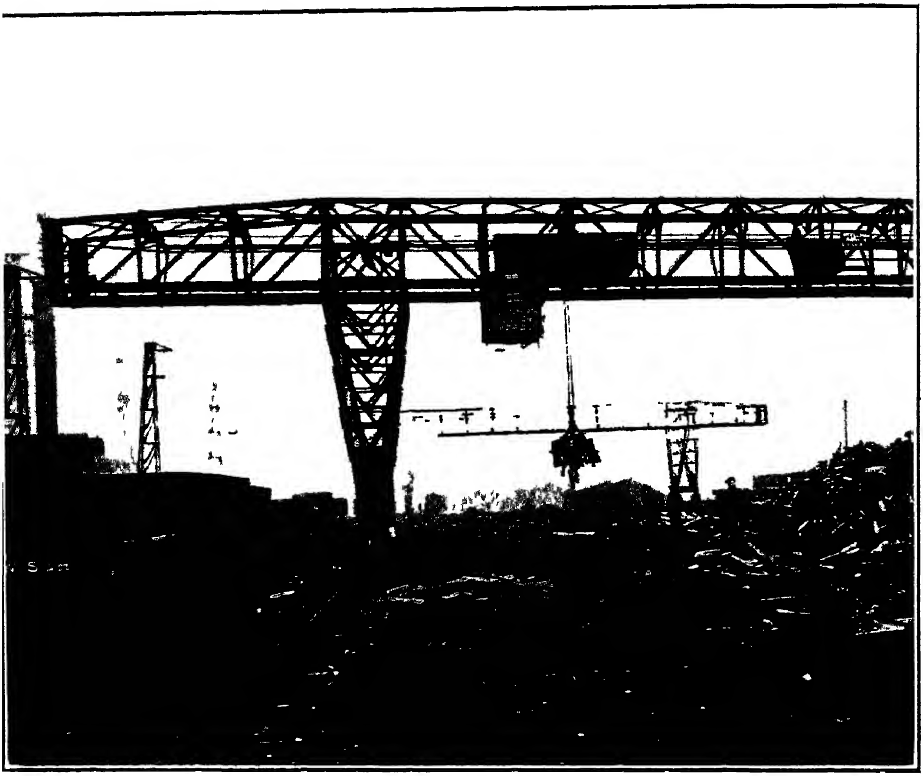


FIG. L16.—Five-ton magnet crane.

amount of time; hence the saving in fuel is considerable. Further, as loss of heat is prevented, time in melting is saved and the output of the furnace increased. Many of the operations could be performed by hydraulic power, but the economy in electric working due to the automatic adjustment between the energy taken and the work done and the simplicity in the connections to the source of power give points to the use of electricity.

Lifting Magnets.—The handling of small and broken pieces of iron by manual labour is a difficult and costly operation, while the picking up of such material by a magnet is simplicity itself; it is only necessary to ensure economy and confidence by the minimum consumption of current and the absolute reliability of the circuits and switchgear. The most popular type of magnet for such work is the Circular "Pot" type, which may be slung from a crane, although a row of small magnets attached to a beam may be used for special work, such as picking up long strips or plates, and show an advantage as compared with the time and labour

TABLE L2

COMPARISON OF DESIGNS FOR MAGNET OF 750 MM DIAMETER WITH TOTAL GAP LENGTH OF 2 CM.

	Dynamo-steel Magnet			Cast iron Magnet
	Copper Winding	Aluminium Winding		Copper Winding
	900 Watts	900 Watts	2,700 Watts	900 Watts
Holding power	1	0 66	1 28	0 45
Weight	1	0 65	0·74	1 00
Cost	1	0 63	0 70	0 61
Weight per kg load	1	0 98	0 61	2 23
Cost per kg load	1	0 96	0 55	1 36

taken in attaching and detaching slings to such articles. The holding power varies with the permeability of the article lifted and the length of the air gap. The weight and efficiency of the magnets has received a considerable amount of attention, and some makers, *e g.*, the Lauchhammer Co., who were at any rate one of the first to do so, use oxidised aluminium wire for winding them. Investigations have lately been made in Germany by M. Pfiffner, as reported in the *Elektrotechn. Zeitschrift.*, 11th and 18th January, 1912, whence the data for the interesting Table L2 is taken. This shows that when a given frame is wound with copper and aluminium respectively there is very little difference if the same energy is used

in each case, but owing to the higher permissible temperature rise the aluminium magnet coil will carry three times the wattage that the copper coil will carry, and its holding power is 28 per cent. greater, while its cost is 30 per cent. less.

Fig. L16 shows a 5-ton Magnet Crane by the Wellman-Seaver and Head Co. handling broken pig iron.

Table L3, giving details of the "Witton Krämer" Lifting Magnet, is from data kindly supplied by Messrs. the General Electric Co.

TABLE L3.

APPROXIMATE CAPACITIES OF LIFTING MAGNETS.

Diameter of Magnet	Weight of Magnet.	Solid Steel Ingots or Armour Plate	Steel Plates	Shafting Bars, Rails, Girders	Pig Iron	Scrap Iron, Broken Castings	Current Consumption per Hour *
Ins.	Lbs.	Tons.	Cwts.	Cwts.	Cwts.	Cwts.	Kw
15	280	1	6—8	5—10	—	—	·8
18	420	2	8—10	10—15	—	—	1·5
24	728	4	12—18	15—20	—	—	2·0
36	1792	6	20—30	20—25	5—6	3—5	4·0
42	3024	8	25—35	25—30	9—12	5—10	5 5
52	4186	10	35—45	30—40	15—20	10—12	6 5
60	7616	12	50—60	40—50	20—30	15—25	8 0

* The current consumption is rated on 60 lifts each of one minute's duration.

Another useful application of the lifting magnet is for handling the huge steel balls which are used for breaking faulty casings and scrap in foundries. In the old style the ball had to be slung and released mechanically very much in the way that a pile-driving ram is handled, but with the electro-magnet the ball can be round without any projections, and is lifted by a pot magnet with a concave face of suitable radius.

CHAPTER XII

ELECTRIC WELDING AND FURNACES

Welding of Metals.—The term welding is somewhat loosely used to cover the two methods of joining pieces of metal, *i.e.*, fusion or casting, and welding. By welding is properly meant the joining by pressure of two pieces of metal when in a plastic state, and it follows from this that the pressure necessary to effect the weld will depend on the temperature of the metal. Cold metals will weld, but that is generally spoken of as "seizing."

Many metals cannot be welded hot, as their passage from a plastic to a fluid state occurs within a relatively small range of temperature. The necessary points to ensure a good weld are :—

(*a*) Proper temperature ;
(*b*) Protection of the metal from oxidation, which is effected by means of a flux sometimes contained in the metal and sometimes added ;
(*c*) Application of pressure sufficient to ensure the extrusion of the flux and clean contact between the parts to be welded.

The last point is perhaps the most important, as unless the pressure and shape of the parts are proper the flux is not extruded completely and the joint becomes partly welded and partly soldered by the fluxed slag.

Apart from the effects of dirt and cinder the slag may be formed by oxidation, so that any means which can be employed to prevent oxidation of the parts makes for sound welds.

In casting a joint sufficient metal must be run in to ensure the melting of the parts to such an extent that the fibres or crystals can thoroughly interlock. The interlocking can only be partial owing to the entrained air and oxidation, which

form bubbles and slag and so prevent intimate contact between the parts at all points.

Metals heated in a fire before welding must be heated under a reducing flame, which helps to deoxidise the skin of the parts ; but the effect is only partial and not under complete control, so that there is always a certain amount of slag due to oxidation, which must be squeezed out of the joint or the weld will not be complete.

This is just where electricity can be usefully employed, as the arc is clean and may be directed so as to carbonise or decarbonise the metal at will. In the early attempts this point was not appreciated, so alternating current was generally employed, and the features which were claimed for the process were cleanliness, saving of time, and neatness, which was due to the instantaneous squeezing of the parts to be welded as soon as the necessary temperature was reached.

Henry Wilde (Roy. Soc. Phil. Trans , 1867, p. 106) first heated up iron wire by the passage of electricity from one of his dynamos and it is only necessary to employ more powerful sources of electricity to heat or melt any section of metal desired.

One of the earliest exhibitions of electric welding in England was on the historic night of 15th April, 1890, when the late Sir Frederick Bramwell turned the theatre of the Institution of Civil Engineers into a smith's shop and showed the Elihu Thomson Welding Machine in operation (Proc. Inst. Civ. Eng , CII., p. 1).

The Thomson machine consisted of a transformer, to the ends of the secondary of which two vices or jaws were connected —one fixed, the other movable. The parts to be welded having been gripped in the vices and the current turned on, the applied pressure "upset" the ends and effected the weld. Such machines are still used for welding wires, rods, tubes, and small standard sections of iron and steel. Thomson's early experiments were made with continuous current, which he abandoned in favour of alternating current, owing to the greater facility it presented for transmitting the energy at high pressure and the saving in weight of the copper connections necessary.

The Prescot Welding System is the Thomson system with mechanical improvements as made by the British Insulated and Helsby Cables, Ltd.

Their *Spot-welding* Machine is a device for electrically welding together two or more iron plates which may be anything from $\frac{1}{100}$th of an inch to $\frac{1}{2}$ an inch in thickness, and in its effect is the equivalent of riveting. By this system a number of small circular spot welds are made, the diameter of the spots varying from about $\frac{1}{8}$ in. to $\frac{1}{2}$ in., according to the thickness of the plates operated upon. To effect the weld two suitably shaped electrodes are brought to bear on the point where it is desired to weld the plates together. These electrodes form the ends of the secondary circuit of a transformer. The welding current, which passes between them when the primary circuit is closed, rapidly brings the plates at this point to welding temperature. The current is cut off as soon as the welding temperature is reached, and the copper electrodes, which are water-cooled, are then moved so as to squeeze the molten metal and form the weld. Single-phase, alternating current is used. Standard machines are wound for a pressure of 200 volts, 50 cycles, but they can be wound to suit any circuit.

The current consumption is extremely low; 1,000 welds approximating $\frac{1}{8}$ in. in diameter on 28 S.W.G. plate only calls for $\frac{3}{4}$ of a B.T U., while 1,000 welds on a $\frac{1}{2}$-in. plate takes 70 B.T.U.

Seam Welding.—When a continuous weld is necessary in lieu of spot welding, a combination of a fixed and rolling arrangement of electrodes is used. The article to be welded is clamped on to a mandrel by a specially shaped vice with four jaws. The mandrel is mounted on a slide, and can be driven to and fro either by belt or by hand power under an adjustable welding roller. The depressing or raising of the roller closes or breaks the primary circuit of the transformer before the secondary circuit is made or broken, which avoids sparking on the weld. Both the mandrel and the roller are water-cooled, and both journeys of the mandrel are used for welding.

These machines are used for welding all sorts of cylinders and cones made of wrought iron or mild steel, and can be adapted

for a large variety of purposes where an invisible joint is required.

The **Tyre Welding** machine made by the British Insulated

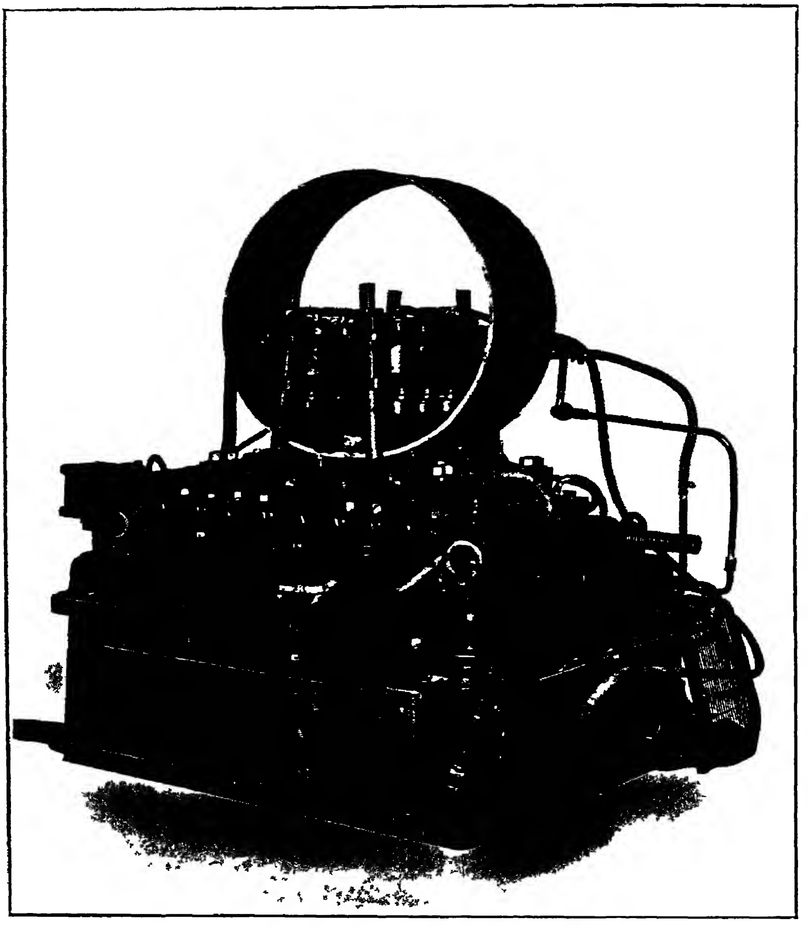


FIG. M1.—"Prescot" welder.

and Helsby Cables, Ltd., works on the same principle as the above-mentioned machines. It is made in various sizes suitable for handling tyres from 10 in. diameter $1\frac{3}{4}$ sq. in. in section and ranging up to 20 in. diameter by 12 sq. in. in section. In all the machines the tyres are gripped in two vices fitted

with jaws which can be changed to suit the radius of the tyre in hand, and which are adjustable both horizontally and vertically, so that the ends of the tyre to be welded may be brought into exact alignment. One set of jaws is movable with a hand wheel in small sizes, and by hydraulic pressure in the large sizes, in order to effect the necessary squeeze and weld.

The jaws form the terminals of the low-tension circuit of the transformer ; all the switching is effected on the high-tension circuit. In the larger size machine, as shown in Fig. M1, the work is held in position by six hydraulic pistons, which also act as terminals to carry the current. They are water-cooled, and may be regulated independently. This is an important feature in operation, as in the event of one part of the weld getting hot too quickly the pressure may be slightly decreased and so the resistance increased. This greatly facilitates uniform heating and reliable operation.

On a large tyre it is easy to think that the resistance all round the tyre would be less than the resistance between the two ends which are squeezed together, but in the case of a small tyre no doubts on this point would be expressed by one who had not tried it. It is interesting to learn that the British Insulated and Helsby Cables, Ltd., applied one of their machines to the welding of wedding-rings, when the resistance across the joint was less than the resistance round the ring, so that welding was effected perfectly and with ease. The system was not successful, however, commercially, as the grip of the jaws injured the gold ring.

Arc Welding.—Messrs. Siemens Brothers scarf-jointed and welded by continuous current small wires for cable work as long ago as 1881 (Proc. Inst. Civ. Eng , CII., p. 47).

About the same time tin plates were electrically welded to the iron plates of a ship by first attaching small patches of tin to the iron plate and then plates of tin were attached to the patches. The iron plate was connected to one pole of a dynamo, and an arc was drawn from the plate to a carbon rod in a handle which was attached to the other pole, the welding being effected under the arc. The bonds of tram rails were welded by the same arc process.

The **Bernados System** of arc welding was brought out in Russia in 1887, or about the same time as Elihu Thomson was working on his machine in America. Bernados used the metal as the negative electrode, and a carbon rod in a portable handle formed the positive pole, the weld or fusion being effected by the arc drawn between the carbon and the metal. The current was supplied by a battery of 490 specially designed accumulators, which were connected in seven groups of 70 cells, the subdivision being arranged to give the necessary volts and amperes for welding, while part of the battery was being re-charged by a shunt-wound dynamo giving 120 amps. at 175 volts. The pressure and current at the arc were adjusted by altering the number of cells.

It was found that the use of the metal as the negative electrode prevented oxidation, but the metal in the neighbourhood of the weld was hardened due to the rapid cooling, so that re-heating or annealing was in some cases necessary.

Various expedients were resorted to in order to overcome the loss in the batteries and the inconvenience attending their use. Instead of groups of cells a simple battery run in parallel with the dynamo was tried. Another arrangement consisted of a heavy resistance run in parallel with a larger dynamo, when the loss in resistance was found to be less than the loss in the battery. An inductive resistance was also used in the circuit, and a dynamo run with a slack belt.

Messrs. Lloyd and Lloyd, now Stewarts and Lloyds, have long employed the Bernados system for welding pipes, casks, &c., and for cutting holes in plates or tubes, the power consumed on the arc being about 60 volts and 300 to 400 amps.

As one electrode is worked by hand the resistance of the circuit is constantly changing and frequent short-circuits occur, in spite of which the simplicity of the Bernados system has made it very attractive, and the difficulty in regulating the current has been met by specially designed self-regulating generators, one of the first of which was that by Dr. Rosenberg.

The **Tudor Accumulator Co.** have made a speciality in the adaptation of the system to the welding of tramway rails, and have taken the question up practically and scientifically

Rails have previously been cast together by pouring around the joint metal heated in a fire according to the Falk process, or by the combustion of ferric oxide with aluminium according to the Goldschmidt process (Thermit); but neither of these processes lends itself to exact work, nor can the quality of the metal at the joint be controlled to suit the exigencies of the case.

The early attempts at welding tramway rails made very unsatisfactory joints. The Tudor Co. first worked with the Rosenberg machine, but their latest equipment is a C.M.B. type of motor generator made by Messrs. Crompton & Co. of 50 k.w. output, giving a maximum current of 500 to 700 amps. The machine runs at 1,100 r.p m. and weighs 34 cwt., the light weight being important, as the machine is fixed complete with the necessary switchboard and resistance in a van. The generator has interpoles, a series winding, an ordinary shunt winding, and an auxiliary winding, which is separately excited and provided with a regulator switch. The motor is compound wound and provided with interpoles The current to supply the motor is taken from the ordinary trolley wire at 500 volts; the same supply is used for energising the separately excited field of the generator.

The Tudor Co. found that when welding steel rails if the rail was made the negative pole carbon was carried into the weld and converted the steel into what was practically white cast iron, owing to the absorption of the carbon by the steel. They therefore work with the rail as the positive and the carbon as the negative pole, and have devised various details and modifications of the process which form the subject of their patents to cover the system, and they are now able, by selecting suitable metals, to make a joint which is practically homogeneous with the rest of the rail and of lower electrical resistance.

In the Tudor Co.'s system a sole-plate is placed under the joint and welded to the bottom flange of the rail and to the fish-plates. The fish-plates are also welded in three places on each side to the head of the rail. If the joint has been badly hammered and is low, their practice is to cut a piece right out of the joint and to weld in a new piece, and with equal ease a gap between the rail ends can be filled up.

Small moulds are put into position where the weld is to take

place, and after the metal of the rail or fish-plate is carefully heated, it is then fused under the arc and suitable metal is dropped in and melted ; in this way the joint can be built up to any degree required, and can be made at will harder, softer, or of the same quality as the rail. After the weld is completed and the metal is set, the moulds are taken away and the extra metal burned off under the arc.

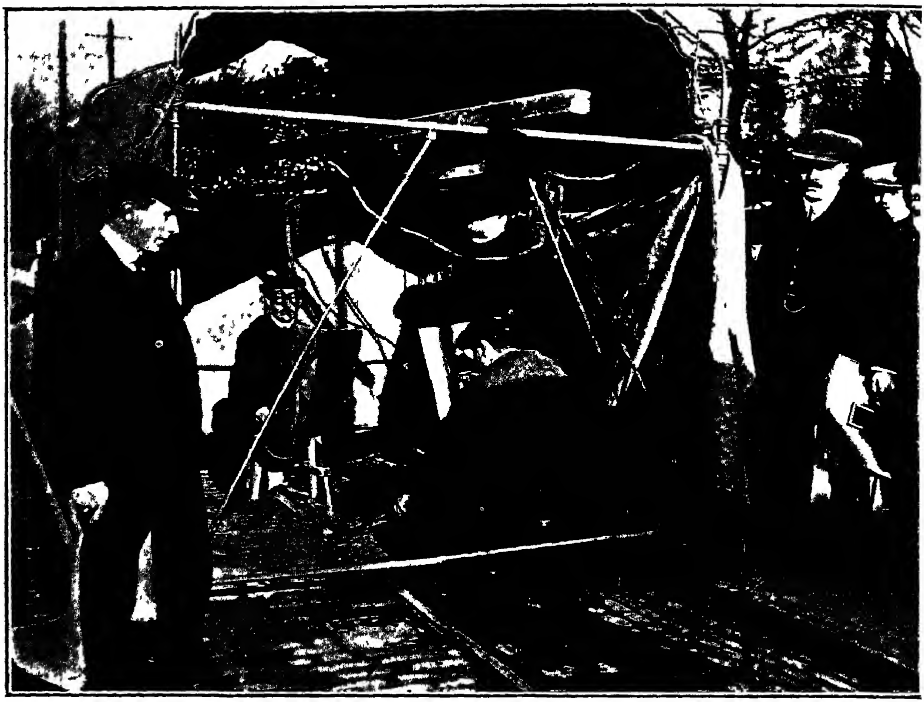


FIG. M2.—Interior of "Tudor" welding hut.

The current supplied by the motor generator set varies from 500 to 700 amps., according to the joint that is being made, the pressure being from 65 to 80 volts. A sole plate fillet $3\frac{1}{2}$ in. by $\frac{1}{2}$ in. by 2 in. is welded in about three minutes.

The Tudor system in operation is shown in Fig. M2. One operator holds the carbon rod while the other applies metal as required. Light sheet iron shields with glass windows are used to protect the faces of the operators.

A large number of tram-lines have been welded up by this process, both in the United Kingdom and on the Continent, and the joints are so strong that breakages owing to shrinkage through cold have occurred in the rail, and not at the joint when rails have been laid and welded up in hot weather.

Dr. Zerener, of Berlin, brought out a system of welding in 1889 in which two inclined carbons were clamped in a holder with a horseshoe electro-magnet fixed above them to drive away the arc from the carbon points. By this means a very long arc or flame was formed, which was regulated by adjusting the position of the electro-magnet.

This system was used for welding joints, plates, &c., the power employed being 100 volts and 30 to 40 amps. The carbons were arranged in a hand tool; subsequently self-regulating apparatus was made which worked at 35 to 250 amps. at 65 volts. Smaller apparatus was used for soldering which took 3 amps. and 40 volts.

The **Coffin** apparatus used in the United States appears to be a direct descendant of the Zerener system.

The **Kjellberg** arc welding process, patented in 1907, has been used to some extent commercially. In this system an electrode consisting of a metal core encased in a coating, the constituents of which serve to prevent the inclusion of foreign matter in the weld and form a reducing atmosphere surrounding the arc and prevent oxidisation of the weld, is used instead of the ordinary carbon electrode. The negative pole is connected to the work to be welded and the positive pole to the electrode, which is clamped in an insulating holder in the usual way. A continuous current of about 100 volts is employed, and the arc takes about 100 to 150 amps. An interesting feature claimed for the system is that the weld can be made on the underside of the work; the molten metal is apparently projected upwards and adheres to the plate. It is usual to hammer the weld to squeeze out any slag which may have been formed in spite of the special coating on the electrode.

An interesting account of repair work with an extemporary

welding rig is given in the *Electric Railway Journal,* 18th November, 1911. The Pittsburg Railway Co. employ the plant, which was all gleaned from their scrap-heap, for repairing all kinds of constructional work with the exception of grey iron castings. Examples are given showing the economies which have been effected by the use of the apparatus, which is worked with a motor generator consisting of an old 30-h.p. shunt motor and a 60-volt, 300-amp. generator.

In the Thomson system the heat is developed at the junction of the parts to be welded by the high resistance of the bad contact; in the other systems the heat is developed by an arc and used either directly or indirectly. These two systems cover the fundamental points in electric welding; the subsequent developments and progress made have been in the application of the systems both as to the mechanical and metallurgical details.

Effect on the Eyes.—The intense arc used for electric welding is very injurious to the eyes, owing to the richness of the incandescent iron vapour in ultra-violet rays; these rays also "sunburn" the skin, so that not only have the eyes of the operator to be protected by special spectacles, but it is necessary also to screen the hands and face by gloves and masks. In fact, it is just the same effect which has been so cleverly recognised and turned to beneficial use by Finsen for the treatment of skin diseases.

The physiological effect of light of different colours has only been studied within the last few years. Formerly red was supposed to be hot, irritating and injurious, and blue cool and soothing; to a great extent this was true—hence purple glasses have been commonly employed and are to a certain extent effective, but they cut off so much light that they render it difficult for the person wearing them to see what he is doing. Further, as red glass transmits red and some orange rays, yellow transmits yellow and some green, blue transmits blue and some green, and violet transmits violet, we may infer that the purple glasses leave something to be desired. The use of apparatus producing arcs rich in ultra-violet rays soon showed that purple glasses were ineffective and led to the more com-

plete study of the subject, following up what had been done in earlier years.

In 1800 Sir William Herschel explored with a thermometer the various colours of the solar spectrum, and found the heating effect increased from the violet to the red end, and the ultra-red rays were hotter than any part of the visible spectrum.

In 1801 Ritter discovered that beyond the violet end of the visible spectrum there were rays which, although invisible to the eye, produced chemical decomposition.

Professor Stokes found that by lowering their rate of vibration the presence of the ultra-violet rays could be made visible, and used paper screens prepared with acidulated sulphate of quinine and other substances, which fluoresced brilliantly when held in the path of the ultra-violet rays.

Tyndall explored the ultra-red rays and plotted their temperature ; he also experimented with the violet end of the spectrum, showing fluorescence and phosphorescence due to the ultra-violet rays. In his experiments he used greenish-yellow glass coloured with uranium oxide, which he found when powdered showed strong phosphorescence , but it has been left to recent years to follow up the experiments and put this glass to practical use. Varieties of it are now on the market which cut off to a marked extent the ultra-violet rays while they are fairly transparent to ordinary light. It is necessary to protect the eyes from glare ; hence a certain degree of opacity to the visible rays is required as well as opacity to the invisible ultra-violet rays.

There are now two systems of protection in vogue :—

(1) Combinations of ordinary coloured glasses built up to suit the work in hand, which are not very transparent to ordinary light, but have given satisfactory results in practical use, with the advantage of being cheap and readily obtainable.

(2) The latest is the use of special " Uranium " glass, the exact composition of which is a trade secret, and of which there are several kinds on the market, *e.g.*, the Chromos, Chloros, Euphos, Flemos, and Hallauer, as used for spectacles.

By the kindness of Mr. Leon Gaster, the author was able

to introduce a screen made of barium platino-cyanide into the invisible portion of the spectrum beyond the ultra-violet, and the existence of the rays was made evident by green fluorescence, the Rowland grating and quartz prisms having been kindly arranged for the experiment by Professor Ernest Wilson. Samples of several of the glasses mentioned were also shown, some of which were loaned by Mr. L. Gaster, others by Mr. Charles D. Burnet, of the Tudor Co.

Those who wish further information on this interesting subject may find it in the Cantor Lectures on "Modern Methods of Artificial Illumination," by Mr. Leon Gaster, 1909.

Electric Furnaces may be looked upon as applications under special conditions of the systems used for electric welding.

Theoretically, the passage from welding to furnaces is very short; practically, the distance is immense, owing to the difficulty in constructing a furnace which combines the essential electrical and mechanical features. The furnace must have strong walls of refractory material which are good heat insulators, and the walls and lining must not disintegrate under working conditions.

The electric furnace is essentially an apparatus in which electricity is passed through a resistance, and so is converted into an intense local heat with the minimum possible loss by radiation and convection. The furnace may be operated either by continuous or alternating current.

1 k.w. hour of electrical energy = 3,420 B.Th.U., so that 4 k.w. hours may be taken as approximately equal in calorific value to 1 lb. of good average coal.

The temperature of combustion of coal is lowered by the specific heat of the products of combustion to an ideal figure of about 4,800° F., which, however, is not realised in practice owing to the excess air admitted to the furnace. The usual temperature attained is only about 3,000° F. with 50 per cent. excess air, or 2,500° F. with 100 per cent. excess air. The highest temperature reached in commercial furnaces using solid fuel may be taken as about 3,000° F., or slightly below the melting point of platinum, which, according to Violle, is 3,227° F.

The electric furnace presents a means of attaining a higher temperature than can be obtained in a furnace fired with solid fuel, as its efficiency is not lowered to the same degree by the loss of heat carried off in the products of combustion.

A very large number of furnaces has been designed or built which differ considerably in detail, but each of which may be referred to one of three main types :—

(1) The **Arc Furnace,** in which the charge or substance to be heated forms one pole of the arc, or in which the charge is heated by the radiation from an arc between two electrodes which are not in direct contact with the charge.

(2) The **Resistance Furnace,** in which the charge or substance to be heated forms part of the electric circuit, or in which the charge is in contact with an electrically heated substance. The former is sometimes called direct, the latter indirect, resistance heating.

(3) The **Induction Furnace,** in which the charge or substance to be heated forms the secondary circuit of a transformer and is heated by the passage of the current induced in it by the primary circuit.

It will be noted that this classification is not thoroughly satisfactory, as if the arc is considered as a gaseous resistance there is no good reason for differentiating between types (1) and (2) ; nevertheless, it is convenient to class furnaces in which the open arc is employed separately from those in which it is not.

Again, in the Induction Furnace, the charge is heated owing to the resistance that it presents to the passage of the current, when it acts as the secondary of the transformer ; but it is convenient to class furnaces in which the primary current is employed directly for the heating separately from those in which an induced or secondary current is used for the purpose.

The Arc Furnace is a development of the Bernados or the Zerener system, and the Induction Furnace is a development of the Thomson system, as mentioned above in connection with welding.

The earliest recorded use of the arc for heating is Sir Humphrey Davy's experimental work in smelting alkaline earths in hydrogen (Roy. Soc. Phil. Trans., 1810, p. 16). This was in the same year that Sir Humphrey Davy first exhibited the electric arc at the Royal Institution. Sir Humphrey depended upon primary batteries for his current, and it was not until the development of the dynamo electric machine that real progress was made.

The earliest form of arc furnace in which any practical work was done is due to Werner Siemens, who in 1878 and 1879 constructed furnaces.

In June, 1880, *Dr. C. W. Siemens, F.R.S.*, read a paper before the Society of Telegraph Engineers (Vol. IX., p. 280), when he exhibited an electric furnace in which he melted 1 lb. of broken steel files in thirteen minutes; a second charge was melted in eight minutes. The furnace consisted of an ordinary crucible with an iron, platinum, or carbon rod passed through its bottom, the cover being pierced for the negative electrode.

Siemens records that if the carbon rod at the top is made the positive pole the detachment of particles of carbon may interfere with the effect. If the top carbon is made the negative the consumption of carbon is very slow and the effect on the metal to be melted is negligible. He also experimented with a tube of copper as the upper electrode, cooling it by forced water circulation.

Siemens showed that on the basis of fuel economy the furnace was more economical than the ordinary air furnace as used in Sheffield, and that it would be nearly equal to a regenerative gas furnace.

At the British Association Meeting in Southampton, in 1882, Siemens and Huntington reported further experiments made with the above furnace which had been improved by the addition of a coil to direct the arc. A long series of metals had been melted and alloyed, including platinum and tungsten, the power being derived from a 12-h.p. Marshall engine, which drove five D2 Siemens machines.

One of the first furnaces erected on a commercial scale was probably the **Cowles Furnace,** which was used in connection with a Crompton dynamo of 400 h.p. to give 5,000 to 6,000 amps.

by 60 volts, for the manufacture of aluminium alloys (*Industries*, 1st September, 1888, p. 237).

The furnaces were in the form of long troughs, the current being introduced at each end by carbon electrodes, to which flexible copper connections were attached by clamps. The e'ectrodes were passed through iron pipes into the furnace, and could be regulated by a screw. The current was passed

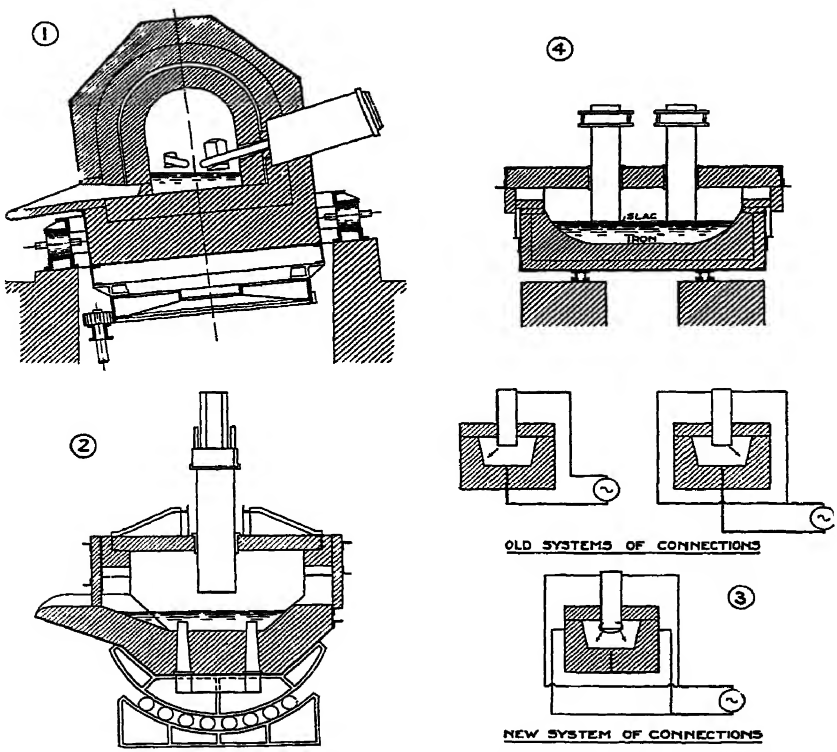


FIG. M3.—1. Stassano, 2 and 3 Girod, 4. Héroult furnaces.

through the charge, part of which was melted and retained in the furnace with the slag, the volatilised portion of the charge being caught and condensed.

The **Stassano Furnace,** as first made in Italy about the year 1898, was in section very much like a blast furnace, but was provided with electrodes in place of tuyères. Stassano followed this with a design of a reverbatory furnace fitted with

several electrodes opposed to each other in pairs above the level of the charge. Striking gear was provided, by which the carbons could be brought into contact and then drawn apart, the metal being heated by direct radiation from the arc and reflection from the roof and sides of the furnace. In his next arrangement (Fig. $M3_1$) the furnace was made circular and so mounted that it could be tilted and revolved to ensure complete mixing of the metals. The first of the revolving type was started in 1903 at the Royal Artillery Works, Turin.

One of the revolving-type furnaces is reported as working in Turin in 1905 employed in melting scrap and refining pig iron; 850 k.w. hrs. was used per charge of 600 kg. on the high-tension side of the transformer, or 772 k.w. hrs. on the low-tension, for which a thermal efficiency of 51·4 per cent. is claimed.

Major Stassano in 1909 recovered his patents from the company who had been exploiting them, and since that date has put down furnaces among others at :—Milan, one 250 k.w. and two 100 k.w.; Liguria, one 800 k w.; Odessa, two 250 k.w.; and three 250 k.w. for the Electro-Flex Steel Co., Newcastle-on-Tyne. A large ironworks is now being erected at Notodden, Norway, which will take 15,000 h.p. from the Tinfos power plant, and furnaces aggregating 5,000 h.p. are expected to be in operation in a few months time.

Further interesting particulars of the Stassano furnace are given in Mr. Catani's Paper read before the Iron and Steel Institute, October, 1911, where an efficiency of 80 per cent. is claimed for a rotating furnace of 200 h.p. when used for refining special steels.

Girod.—In this form of arc furnace (Fig. $M3_2$) one pole, which may consist of one or several carbon electrodes, passes through the furnace crown and touches the slag as in the Héroult steel Furnace, but the current, instead of passing along the layer of slag, goes down through the slag and the charge to the other electrode, which is in the form of an iron ring with studs projecting through the bottom of the bath. The iron projections from the ring pass through the bottom of the bath and are joined in parallel, they are reduced in area at the inside to such a section that they are heated by the passage of the current and

so do not take heat from the molten metal. The lower ends of the connections are water-cooled.

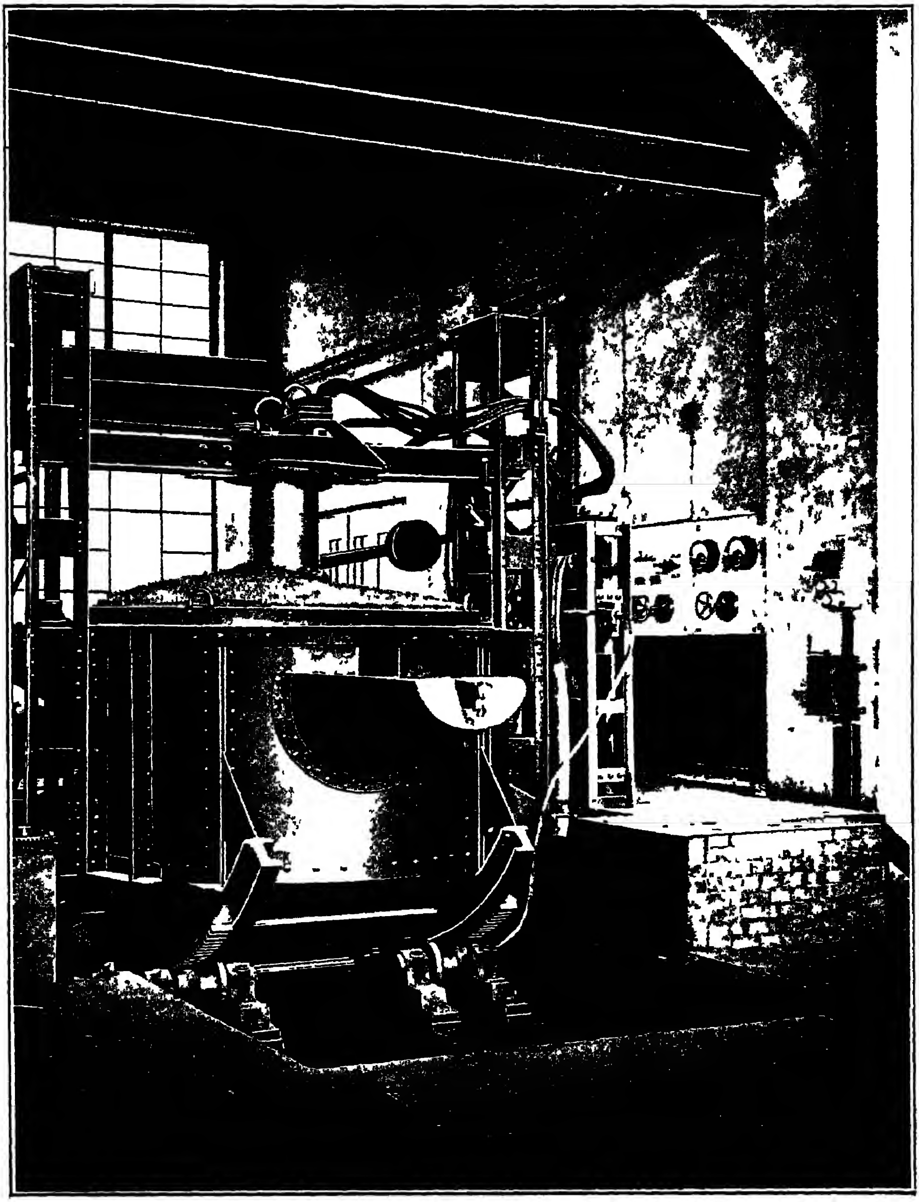


Fig. M4.—Girod furnace.

The furnace is designed for single-phase, alternating current at a pressure of 55 to 65 volts.

A full description of a 3-ton Girod Furnace (Fig. M4) operating at Gutehoffnungshutte at Oberhausen is given in *Stahl und Eisen*, 20th July, and 3rd August, 1911. From this description Fig. $M3_3$ has been prepared, which raises an interesting point regarding the connections, more particularly in view of the experience of Dr. Siemens thirty years earlier. The figure shows the three arrangements of connections which were tried. When the top connection was taken up only one side of the furnace, which is the arrangement commonly adopted, the arc was repelled from the side upon which the conductors are situated to the lining of the roof of the furnace on the opposite side. This led to the trial of the next scheme, when the conductor was divided and taken up both sides of the furnace, but the arc was still repelled towards the lining. The third arrangement was found to be satisfactory, in this both the top and hearth electrode conductors were divided and carried up on both sides of the furnace. The conductors for the hearth electrodes were joined to the iron shell of the furnace, special copper rings and plates being used to ensure a good contact. This symmetrical arrangement has proved quite satisfactory; the arc plays round the upper or carbon electrode and keeps the slag and metal in circulation, and is not so likely to be blown out as in the previous cases. Experience shows that the arrangement saves about 10 per cent. in power, and the carbon electrode burns away regularly. The roof of the hearth, which formerly only stood about twenty heatings, now stands sixty or seventy. The lining of the hearth, for which magnesite was formerly used, is now made in dolomite, and has stood over one thousand heats.

The bottom electrodes project about 4 in. into the bath when new; they partly melt, but this is not found to be a disadvantage, as the molten metal flows into the depression and keeps up the contact. The under side of these electrodes projecting below the bath are connected not only electrically but also to a water-cooling system, and the cooling water is found to carry away about 1 per cent. of the total energy, while the cooling water of the carbon electrode absorbs 3·65 per cent.; hence

in the level of the charge as it settles down. The passage of the two-phase current through the molten metal promotes circulation and avoids the necessity of revolving the furnace or of mechanical means of mixing the metal.

The refractory material with which the bath is lined is a conductor when heated, and is not injured by the passage of the current; the unbroken bottom of the bath, therefore, is claimed as preferable to the risk of leakage which occurs when contacts are passed through the lining.

The electrodes can be automatically regulated and the furnace tipped in the usual manner.

Experiments were made in 1907 with a 300 h.p. smelting furnace at Ludvika which had only a low shaft; a larger furnace was built shortly after with a higher shaft and gas circulation. The current available to operate it was 60 cycle, so a motor generator was employed; this consisted of a 900-h.p., 7,000-volt, three-phase synchronous motor driving a 25-cycle, 300 to 1,200 volt, three-phase generator. Near the furnace transformers were located, which could give 1,500 k.v.a. at a 14 to 1 or a 7 to 1 ratio; the former gave 20 to 85 volts, the latter 40—170 volts. In this furnace the current was so steady that automatic regulation was not found necessary.

The Trolhattan Smelting Plant constructed under the above patents has been in active operation since November, 1910. The furnace, of the type shown in Fig. M5, is a combination of a blast furnace shaft with an electric furnace hearth, and is closed at the top by a charging bell. The height from the ground to the furnace top is 45 ft. The shaft stands upon the roof of the hearth; its weight is taken by heavy cross girders built into the walls, and the joint between the shaft and crown is made by a sand seal.

Four electrodes project through the roof into the hearth at an angle of 65°; each is built up of four carbons 12·5 in. square, 6 ft. 6 in. long. They are water-cooled and packed with asbestos to prevent leakage of gas from the furnace, and are adjustable on a sliding frame.

The electrical energy is taken from the Power Company at 10,000 volts, 25 cycles, three-phase. By means of Scott-connected 1,100 k.v.a. transformers it is transformed into two-phase

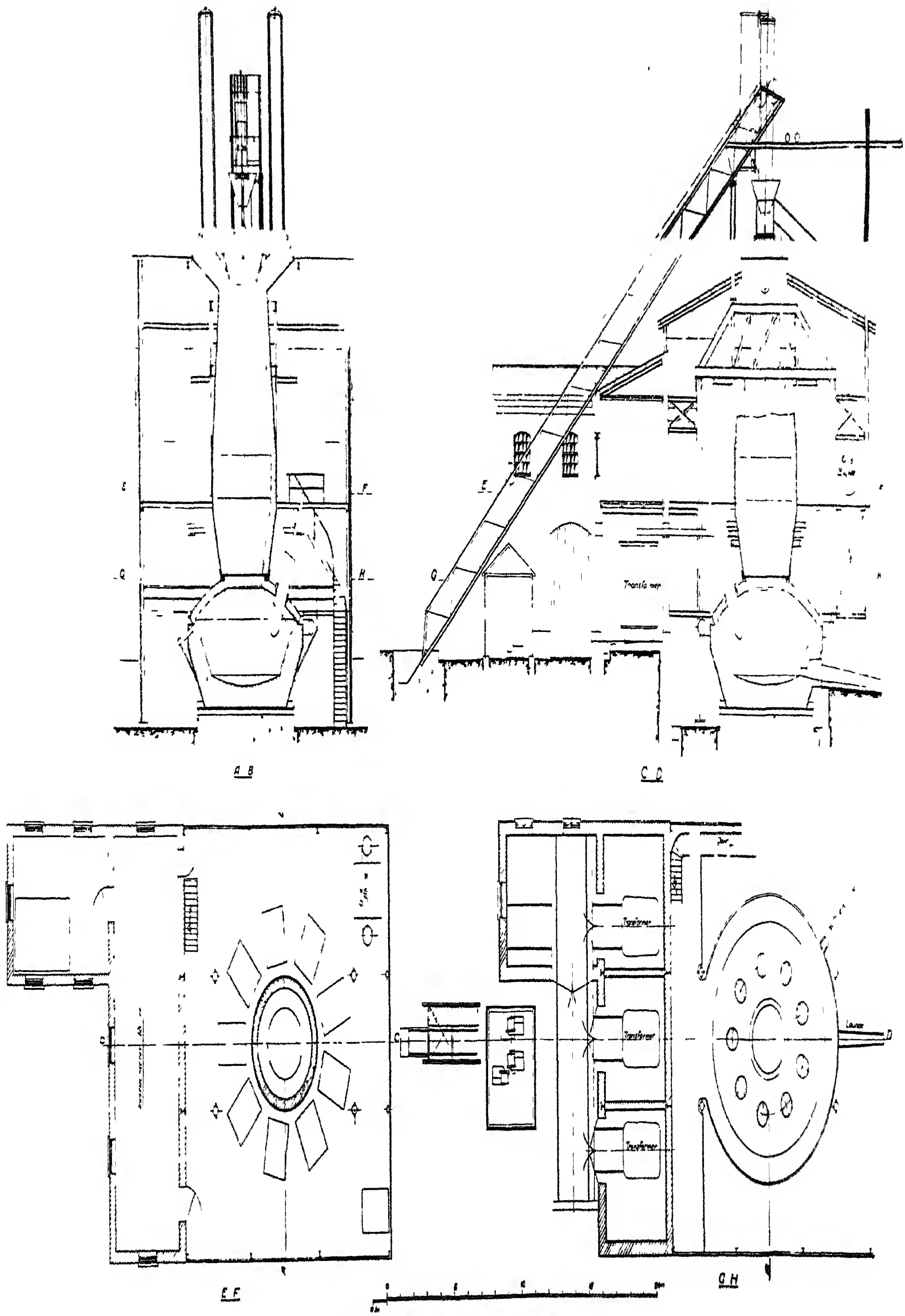


Fig. 135.—Electro-Metal Co.'s smelting furnace.

50 to 90 or 100 to 180 volt current. The current in the furnace is regulated by varying the tension of the supply, which is effected by cutting out windings on the high-tension side of the transformer. The regulating gear controls each phase separately, so that each phase can be worked at a different tension.

There are three furnaces, each of which is designed to make 7,500 tons of pig iron per year of eleven working months out of iron ore with charcoal fuel in the shaft on a nominal rating of 2,500 h.p.

Several tests were made between November, 1910, and April, 1911, which showed on a varying load from 1,121 k.w. to 1,694 k.w. a consumption of 2,150 to 3,800 k.w. hrs. and 920 lbs. of charcoal per ton of pig iron, with an output of about 3·5 tons of iron per kilowatt year. Subsequent tests show a considerable improvement on this figure, as the consumption per ton of pig iron produced has fallen to 1,750 k.w hrs. with 748 lbs. of charcoal.

The price to be charged for electricity per kilowatt year is 29·8*s*. for the first ten years, and after that 39·7*s*.

Furnaces of this type are now in hand aggregating 27,000 h.p., and a further 36,000 h.p. are projected.

The chief claims for this type are based on economy in heating and in repairs—the former because the waste gases resulting from the reactions in the furnace are caught at the top and blown back through the tuyères into the lower chamber and so cool the roof. The fuel, flux, and ore are fed in at the top; the ore is partially reduced by the CO rising through the burden; the process is completed in the lower chamber. As the furnace is only about half the height of a blast furnace, it can be handled more easily and repaired more readily.

The square carbon electrodes removed from the furnace show great irregularity in burning and waste in carbon ends. This has been met by the substitution of round carbons for the square blocks. Round carbons may now be obtained 600 to 700 mm. in diameter with screwed ends, which save a great deal of waste.

Héroult's Direct Resistance Furnace, in which the crucible with the metal to be heated formed one pole and a carbon

introduced from the top into the metal formed the other pole, was the first electrical furnace arranged for continuous working, and has been used for the reduction of aluminium since 1888.

The British Aluminium Co. started their works at the Falls of Foyers, in Scotland, in 1896 and used this process for the electrolytic production of aluminium and carbide. The carbon-lined baths are about 5 ft. by 2 ft. 6 in. on plan, internally, and are connected in series, a current of about 8,000 amps. is employed, the pressure per bath being about 7 volts. As the process is an electrolytic one continuous current is used.

The Héroult Furnace for iron was developed in 1900; in it the carbon electrodes enter the furnace crown and come in contact with the slag which floats on the top of the charge; the slag acts as an electrolyte and completes the path of the current, part of which also passes through the charge (Fig. $M3_4$). Care must be taken that the carbons do not pass through the slag into the metal, which would decrease the resistance between them; arcing between the slag and the electrodes is not so important, but steps are taken to avoid it. The current used is alternating generally single-phase. By this arrangement Héroult saw that he could heat the charge without exposing it to the carbon vapours of the arc, and further that it was possible to remove or introduce any desired ingredients by the addition of suitable slags.

The furnace is also operated on three-phase current at 90 volts. Three 15-ton furnaces of this kind are now in use in America. Details are given in the American Electro-Chem. Soc. Trans., Vol. XIX., 1911, of one at Chicago which is used to produce de-oxidised steel from ordinary Bessemer pig iron. A 15-ton furnace is in use at Skinningrove.

The new furnaces are provided with automatic regulators for the electrodes, consisting of spring-controlled floating magnet coils acting as relays, which put suitable pawls into gear on a rocker wheel which is constantly moving and by which the motors controlling the electrodes are started.

The power-factor of a Héroult furnace working in Sheffield is said to be from 0·95 to 0·97, which shows that the action is that of a resistance and not of an arc furnace.

Induction Furnaces.—The first Induction Furnace design is due to *Ferranti*, who patented one in 1887, which, however impracticable for metallurgical purposes, was the earliest embodiment of this important type.

F. A. Kjellin followed in 1900 with a furnace in the form of a circular masonry trough or hearth, with a space in the centre through which one leg of an electro-magnet was passed; the

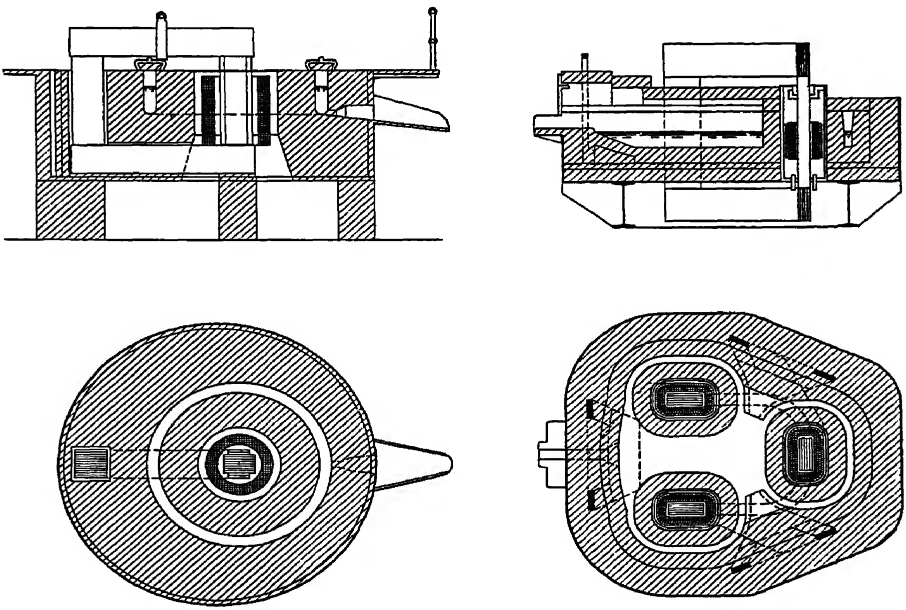


FIG. M6.—Kjellin and Rochling-Rodenhauser furnaces

other leg stood outside the trough, the two being joined by yokes which passed respectively over and under the furnace, so that the furnace hearth and the magnetic circuit which forms the primary of a transformer are inter-linked. The metal in the annular hearth forms a single-turn, short-circuited secondary circuit, the current in which can be regulated at will by altering the current in the primary coil (Fig. M6). The metal in the hearth can therefore be heated by the full value of the electrical energy, as there is no loss, owing to the heavy current passing through electrodes or connections. The

electro-magnet is cooled by water circulation or air blast, as may be most convenient.

The first of these furnaces, of 176 lbs. capacity, was operated at Gysinge in Sweden in March, 1900, when 600 lbs. of cast steel were obtained in twenty-four hours, the energy being supplied by an 80 k.w. dynamo. This furnace was improved until 1,300 to 1,400 lbs. of steel ingots were produced in twenty-four hours with 58 effective k.w. The charges were about 220 lbs. each.

In the second and larger furnace, which was started in May, 1902, an output of about 4 tons of steel was obtained per twenty-four hours with 225 electrical h.p. effective.

The **Rochling-Rodenhauser Furnace**, which has been developed from the Kjellin at the Röchling Steel Works, Völklingen, is another successful example. The first design was made in 1906 after operating a Kjellin furnace. Recognising the greater general usefulness of three-phase current, Mr. Rodenhauser worked out his design to suit three-phase as well as single-phase.

The three-phase design is shown in Fig. M6. It will be noticed that the hearth is somewhat heart-shaped in outline, and by the insertion of three transformer limbs is divided into three narrow channels with one common basin in the centre. The narrow channels form the secondaries of the transformers and are short-circuited by the centre basin.

The chief difference between the Rodenhauser design and the Kjellin is the combination with the induction furnace, in the former, of a separate secondary circuit wound directly over the primary winding on the transformer, the ends of which are connected to blocks embedded in the refractory walls of the hearth. The walls become conductors of electricity when highly heated, so that they and the molten metal then complete this circuit, and, in addition to the ordinary secondary currents in the hearth, other currents are flowing between these blocks, which keep up the heat of the bath and also mix the metal. It is stated that about 70 per cent. of the energy used is induced directly in the bath and the remaining 30 per cent. in the auxiliary circuit.

The hearth is covered in and provided with doors, through which the working of the furnace may be watched or ingredients added.

In arc resistance furnaces of the Girod type the whole of the current has to pass through the refractory lining, which stands up well to the treatment. In the Rodenhauser furnace only part of the secondary current passes through the lining, and the wear and tear is found negligible ; in fact, these parts last longer than any other part of the furnace lining.

Some of the earliest experiments at Völklingen were made with a 5-cycle machine, consisting of a six-pole Siemens-Schuckert generator driven by an Escher-Weiss horizontal tandem compound engine, which was exhibited in the 1900 Paris Exhibition. Mr. Rodenhauser's combination of the second secondary circuit improved the power-factor, so that when operating on a 25-cycle supply a 3-ton furnace has a power factor of 0·80.

The furnace is fully described in a paper by Mr. Rodenhauser (Journal of the Iron and Steel Institute, 1909), where operating details are given of an 8-ton, 600 k.w. single-phase furnace working on the 5-cycle machine, and a $3\frac{1}{2}$-ton furnace taking 200 to 250 k.w., three-phase energy, at 50 cycles from the ordinary power circuit of the works.

The 8-ton furnace had been running since November, 1908, with an average output of 1,200 tons of rails in fourteen days before the lining required renewing.

The $3\frac{1}{2}$-ton furnace is reported as having worked for a whole year producing steel for rails of which more than 500 tons have been sold. The electrical efficiency of the $3\frac{1}{2}$-ton furnace is given as 97 per cent. The consumption of energy per ton of metal is stated as under :—

Cold pig and scrap	600—900	k.w. hrs.	per ton.
Hot pig and cold scrap ..	300—700	,,	,,
Hot metal from converter..	250	,,	,,
Hot metal from the open-hearth furnace	200—250	,,	,,

The energy per ton and the length of time that the metal has to remain in the furnace depend on whether the furnace is

charged with cold or hot metal and upon the amount of refining necessary. A round figure is given as to the operation of an 8-ton furnace in which about 50 tons of Bessemer open-hearth steel can be refined in twenty-four hours with a consumption of 300 k.w. hrs. per ton.

The **Frick Furnace** is of very much the same type as the Kjellin, but the primary windings in the Frick are placed over and under the hearth, and not in the centre, as in the Kjellin type. Messrs. Krupp have a 1,000-h.p., 10-ton furnace of this type at Essen working on single-phase supply.

The **Hjorth Furnace** is of the induction type, in which one transformer primary coil is common to two hearths, which form the secondary alternately as they are filled with the molten metal which is to be refined. It is built under American patents dating from 1904.

The **power-factor** in the early types of furnaces was low. In the arc furnace, due to the back E.M.F. in the arc, which causes a lag, the power-factor must be lower than that of a resistance furnace, but the power-factor of the induction furnace is worse than that of the arc furnace. Later designs of induction furnaces show an improvement on the earlier designs, but in any case the wide air gap and the necessary departure from the usual rules for designing a transformer must prevent a high power-factor being obtained. It must be borne in mind that the transformer for an induction furnace consists of a water-cooled iron core, a primary circuit insulated with air and brickwork, and a secondary circuit of molten metal and slag.

Average figures for the power-factor are about as under :—

Resistance Furnace.	Arc Furnace.	Induction Furnace.
0·95—0·97	0·80—0·90	0·60—0·70

The lower power-factor in the induction furnace is in a measure off-set by the steadier current which is drawn from the supply, as in the induction type there is an absence of the heavy surges characteristic of an arc furnace. This difficulty in working arc furnaces is being met by automatic motor control of the electrodes or of the individual generator, when each furnace is provided with its own generating unit.

Rating.—The rating of furnaces is somewhat confusing; some types are rated by horse-power and some by capacity. Catani rates the Stassano furnace which takes a charge of 4 to 4½ tons as 1,000 h.p., while Frick rates his 10-ton furnace also as 1,000 h.p. Rodenhauser's 8-ton furnace takes an input of 600 k.w. = 800 h.p., and Hjorth's 5-ton furnace takes an input of 500 k.w. = 670 h.p. Hjorth has lately designed a 30-ton furnace to operate on three-phase 8-cycle energy with a power-factor of 0·5, which will be supplied by one generator giving 3,540 amps. at 230 volts, though occasionally 4,300 amps. will be called for; this, on normal rating, is 30 tons for 710 k.w. = 950 h.p.; there is, however, no record of these calculations having been verified by the construction of the furnace. The 3-ton Girod takes 500 k.w. and the 12½-ton takes 900 to 1,000 k.w. or 3 tons for 670 h.p. and 12½ tons for 1,270 h.p.

The difference in the ratings appears to be due to the current density at which the particular size or type of furnace can be worked. In some furnaces there is ample provision for absorbing the heat due to a high density, but the "pinch effect" prohibits the use of such a current density as would develop the heat.

The "pinch effect" is the name given to the alteration in the level of the metal in the bath due to its being contracted or pinched by the passage of the current through it. The effect is magnetic and cumulative when it occurs at a point; the metal becomes denser and so of lower resistance; more current then flows, which increases the effect, until in a thin bath the circuit may be momentarily broken.

The makers of induction furnaces claim advantages for their system in that the heavy cost of the renewals, as also the loss of energy in the electrodes, is avoided. An important point, too, is the absolutely clean heat which is provided quite free from carbon or from other impurities. Any ingredients which can be added in an arc furnace can be added in an induction furnace with greater exactitude, as the heavy slag covering is not necessary. In fact, in furnaces of the Röchling-Rodenhauser type, it is impossible to work with a heavy slag, as, owing to the peculiar shape of the hearth, the slag cannot

easily be removed ; hence the furnace can only be used for the refining of metals which are comparatively pure. This point is claimed by the arc furnace makers as a feature in favour of their system, but, as in other operations, one furnace is not best for everything ; each type has its own field for which it is most suitable.

It seems to be open to question whether some electric furnaces have been or are being judiciously used, and whether attempts are not being made to reproduce in them effects which are more natural in an open-hearth furnace. The induction electric furnace is essentially a clean furnace, and so seems better suited for melting than for refining purposes. Where heavy slags, or indeed any slag is worked, ample space must be allowed for its formation and control, and the provision of such space seems inconsistent with the design of a commercially efficient transformer of such abnormal construction as the exigencies of the case call for.

Tempering Furnace.—A new electrical Tempering Furnace was described in a paper read before the Faraday Society, 30th March. 1909, by Messrs. Sabersky and Adler. It is made by Messrs. the A. E. G. Co., of Berlin, and has been very largely supplied to tool makers. They also use it in their own works, and find that the life of milling cutters hardened by this means is considerably longer than the life of cutters hardened in a gas or ordinary furnace.

The bath consists of a fire-clay crucible, which is cubical in its dimensions and is set in an iron framework and packed round about with non-conducting material. One flat plate electrode is placed on each of two sides of the bath. These electrodes are made of Swedish ingot iron, and are practically the size of the inside of the bath. The bath is filled with metal salts which vary in composition, depending on the temperature desired. A bath consisting of three parts of barium chloride and two parts of potassium chloride can be controlled from 1,400° to 2,100° F. ; to prevent electrolytic effects alternating current must be used, which is supplied by a transformer with suitable tappings for regulating purposes. The metal salts are non-conductors when cold, so that the bath has to be started

with an auxiliary electrode, which is used to short-circuit the two iron plates. As soon as the salt melts at the point of the movable electrode it is drawn across the bath, leaving a molten trail of metallic salts, which acts as a conductor and starts the flow of current from one iron electrode to the other. The current continues to pass until the whole of the salts are melted and the bath is raised to the desired temperature. A current of any frequency between 25 and, say, 60 cycles may be applied; with less than 25 cycles electrolytic phenomena appear. When the salts are melted the voltage necessary to maintain the temperature varies from 5 to 30. The voltage when heating up is about 70.

In order to ensure accurate results in hardening the question of temperature is very important; a thermo-couple type of pyrometer is used for the purpose, which consists of platinum and platinum-rhodium suitably protected from the action of the salts. The E.M.F. on the thermo-couple is read on a dead-beat moving coil galvanometer calibrated to read up to 3,000° F.

The advantage of heating up in a bath of this type as compared with an ordinary furnace is that the edges and thin parts of tools do not get hotter than the body of the tool. Preliminary slow heating up is recommended before the main heating takes place. The preliminary heating is advantageous, and gives better results than if the cold tool were plunged direct into the high-temperature bath. The electric bath is, to a certain extent, self-regulating, as when the tool is dipped into the salt the level rises and the resistance of the bath drops, so that the current and heat increase automatically. The bath must be ample in sectional area as compared with the size of the tools or pieces to be dealt with; otherwise the resistance of the tool may be less than that of the liquid, when the current will flow through the tool and the temperature of the bath fall. If necessary the current can also be regulated by the switch connected to the tappings of the transformer.

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